LEWIS'S PRACTICAL SERIES.

MEDICAL ELECTRICITY.

MEDICAL ELECTRICITY

A

PRACTICAL HANDBOOK

FOR

STUDENTS AND PRACTITIONERS

BY

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FOURTH EDITION, WITH ILLUSTRATIONS.

LONDON
H. K. LEWIS, 136 GOWER STREET, W.C.
1904

PRINTED BY
H. K. LEWIS, 136 GOWER STREET
LONDON W.C.

PREFACE TO THE FOURTH EDITION.

The whole of the subject matter has been carefully revised in this edition and much has been added.

The utilisation of current from the mains for medical and surgical purposes is dealt with at length in a special chapter. A chapter on high frequency electricity has been added, and the portion which deals with X ray work has been amplified.

I wish to record my indebtedness to the *Archives d'électricité médicale*, and to Professor Bergonié, its able editor, for many valuable papers and references. Also to the writings of Dr. Bordier, Dr. Castex, and Professor Leduc, and many others.

The valuable course of Lectures to medical practitioners on Physics Applied to Medicine, delivered in Birmingham by Sir Oliver Lodge this year, is of great significance as an illustration of the improved position which is slowly being gained by Electro-therapeutics.

My best thanks are due to all those who have lent blocks for illustrations, and by doing so have rendered me valuable assistance.

In an appendix will be found a list of towns and places having a public electric light supply, with some details of the character of the current furnished.

143 Harley Street,
September, 1904.

CONTENTS.

CHAPTER I.

Historical.

CHAPTER II.

First Principles and Definitions.

CHAPTER III.

The Induction Coil.

CHAPTER IV.

Medical Batteries and Apparatus.

CHAPTER V.

The Utilisation of the Electric Light Mains.

CHAPTER VI.

Electricity of High Potential. Statical Electricity.

CHAPTER VII.

Electricity of High Potential. High Frequency Phenomena.

CHAPTER VIII.

The Electric Bath.

CHAPTER IX.

Physiology.

CHAPTER X.

Diagnosis.

CHAPTER XI.

General Therapeutics.

CHAPTER XII.

Electrical Treatment in Diseases of the Brain and the General Neuroses.

CHAPTER XIII.

The Spinal Cord and Nerves.

CHAPTER XIV.

Other Conditions in which Electrical Treatment is of Service.

CHAPTER XV.

Electrolysis.

CHAPTER XVI.

Cautery and Lighting Instruments. Lamps for Therapeutic Uses. The Electro-Magnet.

CHAPTER XVII.

The Röntgen Rays.

APPENDIX.

PLATES

LIST OF ILLUSTRATIONS.

MEDICAL ELECTRICITY.

CHAPTER I.

Historical.

Origin of the word Electricity. Dr. Gilbert of Colchester. Early medical writers. Remak and Duchenne. Position of electricity in medicine.

1. **Origin of the word Electricity.**—The foundation of the modern science of electricity may be considered to have been laid by a medical man, Dr. Gilbert of Colchester, Physician in Ordinary to Queen Elizabeth and President of the Royal College of Physicians in the year 1600, the date of the publication of his treatise *De Magnete*.

He extended to a large number of other substances the ancient observation that rubbed amber attracted light bodies. It seems also that we owe to him the word Electricity, for he called all those substances Electrics, which when rubbed displayed the same attractive power for light bodies as amber (ἤλεκτρον, electrum) does, and soon afterwards the word electricity was introduced to indicate this power considered as a quantity capable of measurement.

Dr. Gilbert does not seem to have attempted to apply his knowledge of electricity in any way to medicine, but he will always be remembered as the pioneer in the scientific investigation of electricity and magnetism. Dryden has immortalised him in the following lines:—

> "Gilbert shall live till lodestones cease to draw
> Or British fleets the boundless ocean awe."

2. **Early medical writers.**—It was more than a hundred years after Gilbert's time that electricity was first brought into use as a curative agent, and in the early applications of electricity to medicine the statical apparatus was the only form used because it was the only one known, but for many years after

the discoveries of Galvani and Volta statical electricity still remained in exclusive possession of the field of electro-therapeutics.

De Haen (1745), Jallabert (1748) and the Abbé Nollet (1749), were the first to apply statical electricity to medicine.

In 1758, Benjamin Franklin relates that in consequence of the cures reported to have been made in Italy and Germany, a number of paralytics were brought to him for treatment from various parts of Pennsylvania and the neighbouring States.

In 1759 the Rev. John Wesley, the famous divine, collected a number of cases in which electricity had been tried, and published a treatise entitled *The Desideratum, or Electricity made Plain and Useful, by a Lover of Mankind and Common Sense.* In this are given the details of a vast number of cases treated by electricity. Among them he mentions that electricity accelerates the passage of calculi through the ureters. He also relieved tertian and quartan fevers, and hysteria.

In 1777, Cavallo published in London a complete treatise on electricity in theory and practice, with original experiments. It included general remarks relating to Medical Electricity.

The first records of electrical treatment at a London hospital seem to have been in the year 1767, when an electrical apparatus was ordered for the Middlesex Hospital. And ten years later, in 1777, an electrical machine was purchased for the use of the patients in St. Bartholomew's Hospital.

A treatise on the subject of medical electricity by Mr. John Birch, Surgeon, is to be found in a book called *An Essay on Electricity*, by John Adams. The fifth edition of this book was published in 1799, and in it Birch's essay occupies fifty pages. He was attached to St. Thomas's Hospital, where he had charge of the electrical department.

In England, in the earlier half of the past century, the work of Addison (1837), Golding Bird (1841), and Gull (1852) at Guy's Hospital, must be noted. Accounts of what was done by them may be found in the Guy's Hospital Reports for those years, or in Dr. Monell's* book, in which they are reproduced in a slightly condensed form.

Golding Bird also published some lectures on Electricity and Galvanism in 1849, and this marks the transition period from

* "Manual of Static Electricity in X-Ray and Therapeutic Uses." S. H. Monell, M.D., New York, 1897.

the dominance of Statical Electricity in therapeutics, to that of battery and induction coil currents.

3. **Remak and Duchenne.**—Remak in Germany, and Duchenne in France, laid the foundations of the modern modes of treatment by the battery (galvanism), and the induction coil (faradism). The former devoted his attention chiefly to battery currents, while the latter advocated the use of the induction coil in almost all of the conditions for which he employed electricity at all. It is to Duchenne* that we owe the principles of applying the currents directly to the affected nerves or muscles. Duchenne also showed that the muscles could be most easily excited at certain points on the surface of the body, which he called *points d'élection*. These points were shown by R. Remak and von Ziemssen to be places near those at which the motor nerves enter the muscles. They are now called "the motor points."

About 1850, Du Bois Reymond and Pflüger demonstrated the electrical phenomena of living nerve and muscle, and established the laws of electrotonus, the phenomena of the contractions of muscle, and the existence of muscle currents. Remak wrote upon the catalytic effects of the galvanic current, viz., upon the use of continuous currents for the relief of congestions and chronic inflammatory processes, effects which we should now probably speak of as due to a vaso-motor action.

4. **Position of electricity in medicine.**—It is now one hundred and fifty years since the beginning of Medical Electricity. During the whole of that time it has made steady progress in the face of many difficulties, and among these has been the passive resistance of medical men themselves. The vitality which it has shown under adverse circumstances is full of good omen for the future. Medical electricity will continue to advance with the advance of general electrical knowledge. To those who have followed its developments, the progress achieved in the past decade is enormous. The house to house distribution of electricity by Electric Light Companies, has called into existence a large number of new instruments and methods, by providing a constant and steady supply of current

* "De l'électrisation localisée, et son application à la pathologie et à la therapeutique, par courants induits et par courants galvaniques, interrompus et continus." (Translated in an abridged form for the *New Sydenham Society* by Dr. G. V. Poore, under the title "Selections from the Works of Duchenne").

without the need of batteries. The introduction of the secondary cell or accumulator into general use has also been of great service, by affording a simple means of obtaining electrical currents for the use of surgeons. Further, the notion of the treatment of disease by physical means has become familiar to medical men, and the uses of such means are advancing rapidly in favour. Baths, active and passive exercises, electric light baths, radiant heat baths, exposures to ultra-violet light rays, and exposure to the open air, are all called in to-day as healing agents. Considerable advances have been made towards the recognition of the good effects of electricity in general therapeutics, as distinguished from its use for merely local applications, and it is now clear that the "localised electrisation" of Duchenne, and of his school, covers only a part of the ground belonging to medical electricity.

The discovery of the X rays by Röntgen in 1895, and the practical application of them to medicine and surgery which immediately followed, have also added a new and important branch of work to the applications of electricity to medical practice. The use of X rays for diagnosis is now supplemented by their use for purposes of therapeutics, and they have already proved of great value in this direction, and may lead in the future to important developments. Not only are X rays valuable in themselves, but by their effect in bringing electrical apparatus into more extended use among professional men, the establishing of X ray apparatus in numerous instances has led to an increased study of electro-therapeutics. Most of the London Hospitals now have an electrical department, more or less efficiently equipped, and these are of manifest utility. At St. Bartholomew's Hospital over six hundred new patients are referred yearly to the electrical department from all quarters of the hospital.

The treatment of lupus by the light of the electric arc, as introduced by Professor Finsen of Copenhagen, has placed phototherapy, or treatment by light, on a practical basis, and light of various qualities and colours is now being tried quite extensively for various morbid conditions. Inasmuch as electrical currents are used as the source of these various light rays, they will need to be considered in their proper place in this book.

High frequency discharges, which were brought prominently

into notice by Tesla and D'Arsonval in about the year 1890, received little attention when first introduced, but of late years, especially since large induction coils have come into general use for X ray work, the production of high frequency currents has been much simplified, and in consequence they have been extensively adopted for medical treatment.

CHAPTER II.

First Principles and Definitions.

Electroscopes. Conduction. Electromotive Force. Capacity. Condensers. Leyden Jar. Contact electromotive force. The Voltaic cell. Electrolysis. Resistance. Ohm's Law. Units of measurement. Heating effects. Thermoelectricity. Primary and Secondary cells. Magnetic field. Galvanometers. Electromagnetic induction.

5. **Division of the subject.**—The Science of Electricity may best be divided into four branches, as suggested in Dr. Oliver J. Lodge's "Modern Views of Electricity," a book which should be read with care by everyone who wishes to have correct notions concerning the science. These four divisions are:—

a. Electricity at Rest, or Static Electricity.—This branch coincides with that portion of the science formerly treated of as "Frictional" electricity, because the phenomena were most readily observed with electricity at high potentials, such as could be produced by "Frictional" machines. It deals with the properties of electrically charged bodies, and with the phenomena of their charge or discharge.

b. Electricity in Locomotion, or Current Electricity, which deals with the flow of electricity along conductors.

c. Electricity in Rotation or Magnetism.

d. Electricity in Vibration or Radiation.

We need to consider fully the two first of these branches, and especially the second. In the third branch we shall have touch upon magnetism in order to make clear the nature and principles of certain electrical machines and measuring instruments.

The fourth branch has come into the sphere of practical utility through the employment of electric radiations for the transmission of signals to a distance without wires. The discovery of electric radiation, and the first demonstrations of the transmission of electric waves to a distance without wires, were the work of Professor Hertz. Electricity in radiation is also concerned in the phenomena of the X rays.

The whole subject of Light may be regarded as coming within the scope of this fourth division.

6. **Static electricity.**—The study of the ancient observation that rubbed amber acquires the property of attracting small particles of matter has been the starting point of our knowledge of the science of electricity. The experiments which illustrate the steps by which our information has been obtained, are described in the textbooks of electricity.

All bodies, when rubbed with suitable precautions, are, to use Gilbert's term, *electrics*, or rather we should say, that whenever any two bodies are rubbed together electrical separation occurs, one body becoming positively, and the other negatively, electrified, although in many cases it is difficult to observe this, owing to the escape of the charge. In fact it is possible to arrange all substances in a list, such that when any pair of them is rubbed together, the body higher in the list is positively electrified, while the other is negatively electrified to an equal extent.

Such a list is as follows:—Cat's fur, polished glass, flannel, leather, wood, paper, silk, shellac. Thus:—Glass rubbed with cat's fur will be negatively electrified, while the same glass rubbed with silk will be positively electrified.

Positively electrified bodies repel each other, and negatively electrified bodies repel each other, but a positively electrified body and a negatively electrified body attract one another.

Any instrument by which electrical separation is produced may be called an electrical machine. For simple experiments, a glass rod which is rubbed with a piece of silk is such a machine.

7. **Hypothesis of fluids.**—Various hypotheses have been put forward to account for this action; two of these may be noticed, as they supply a means for expressing electrical facts, though it must always be carefully remembered that in using these modes of expression, we are making no assumptions as to the truth or the reverse of the hypothesis, but merely using a convenient analogy. The first is the "two fluid" theory of Symmer, in which it is assumed that all matter contains an inexhaustible supply of a so-called electric fluid, which is capable of being split up, by friction or otherwise, into equal quantities of two fluids of opposite properties, viz., the so-called vitreous (positive) and resinous (negative) electricities, and bodies that display the properties that we have said are signs of electri-

fication, are said to be charged with a certain quantity of one or other of these fluids, a certain quantity of positive or negative electricity. This hypothesis gives us, in many cases, a convenient method of expressing the facts, provided always that it be used as such, and is not pushed to the point of considering that the electric fluids are any real entities, or have any actual existence. It is obvious that it is an essential part of the hypothesis that both fluids shall always be produced in equal quantities.

In the "one fluid" theory, which was favoured by Franklin, bodies that were positively electrified were looked upon as containing an excess of electric fluid, bodies that were negatively

Fig. 1.—Stewart's Gold Leaf Electroscope.

electrified were looked upon as suffering from a deficiency, while all bodies in the normal neutral state were looked upon as having neither an excess nor a deficiency.

8. **Electroscopes.**—The simplest means by which we may tell when a body is electrified, is an instrument called an electroscope. The usual form of electroscope is that known as the gold leaf electroscope, which is made of two strips of gold leaf hung together from a wire. When these are electrified they repel each other and diverge, and so indicate the presence of electrification. The instrument is usually enclosed in a glass jar, which serves as a support and protects the gold leaves from disturbances by currents of air (fig. 1). This figure represents

the electroscope in its simplest shape, but many elaborated and improved forms have been devised.

With this instrument one can also discern the sign of the charge on an electrified body, for if a portion of the charge be transferred to the electroscope, and an additional charge be added from a positively electrified body, *e.g.*, from a glass rod that has been rubbed with silk, then if the former charge was negative, the leaves will collapse, but if positive, they will diverge still further.

The best way of carrying out this test is as follows:—Approach the charged body to be tested to the electroscope. The leaves will diverge. Touch the plate of the electroscope with the finger for an instant, and they will collapse, but on subsequently removing the body to be tested, they will again diverge under the effects of a charge of opposite sign to that of the body to be tested. Now bring up near the electroscope a rubbed glass rod, if the leaves collapse, the present charge is negative, and that of the original charged body was, therefore, positive. The reasons for this procedure will be understood from the next paragraph but one.

9. **Conduction.**—If an electrified body, supported by silk strings or by a glass stem, be connected with another similarly supported non-electrified body by means of a wire for an instant, the second body will be electrified in the same sense as the first body, but to a less degree; the charge of the first body being conducted along the wire connection, and divided between the two bodies. If connection had been made with a glass rod, a stick of resin, or a silk thread, no transfer of charge would have occurred. The metal wire is, therefore, a *conductor* of electricity, the glass rod, &c., are not, they are *insulators*.

Substances vary very much in their power of conducting electricity, thus metals are good conductors, water and the body are fairly good ones, wood and cotton are poor conductors, while wool, silk, oils, resins, dry air, and most kinds of glass, are good insulators.

10. **Induction.**—A conductor can be electrified either by a transfer of electricity between it and another conductor, or by an alteration in the distribution of the electricity on its surface, without any transfer of electricity between it and another conductor. In the former case the body is said to be electrified *by conduction*, in the latter *by induction* or *inductively*.

Induction effects are produced whenever an electrified body is brought near any other body, and we may say, in the language of the two fluid theory, that an electric charge in any body disturbs the equilibrium of the neutral fluid in the bodies near it, attracting an equal quantity of the fluid of opposite sign to their nearer sides, and setting free an equal quantity of the fluid of similar sign to itself at their remoter ends. On the removal of the inducing body, the induced charges recombine and disappear. If before the removal of the inducing body, the conductor be touched with a finger, or otherwise be connected for a moment to earth, then that component of the induced charge, which is of like sign with the inducing charge, will escape, and the subsequent withdrawal of the inducing body will leave the conductor charged with a charge of the opposite sign.

11. **Electric quantity.**—Hitherto in this chapter the consideration of quantity of electricity has been left in the background, and electrification has been spoken of rather as a state or quality super-induced in bodies by certain processes. It is now necessary to arrive at a definite conception of this state as a measureable quantity, *i.e.*, as brought about by the presence of a real or hypothetical something which can be measured, and which is called electricity, a something which has been referred to, for convenience sake, in the language of the "fluid" hypothesis as if it were an actual fluid, but which, it must be borne in mind, is not that, whatever else it may be. Let us suppose the existence of a something which is measureable, and which, when present in any body, endows it with the properties just described under the name of electrification, and which is called Electricity. This electricity then is of two kinds, one named positive, and one negative. It has been seen already, that positive electricity repels positive, and that negative repels negative, while positive electricity attracts negative, and *vice versâ*. This has to be expressed in terms of some unit, to be chosen once for all.

Maxwell (" Electricity and Magnetism ") gives the following definition :—*Unit of Quantity.*—" That quantity of electricity which, when supposed collected at a point, will repel an equal quantity of similar electricity collected at a point, and placed at unit distance from the first, with unit force, shall be taken as the unit quantity of electricity."

In this definition the unit quantity of electricity is made to

depend on the units of length and of force, and this latter is defined with reference to the units of length, mass, and time. Hence the unit quantity of electricity can be completely defined in terms of the units of length, mass, and time. For scientific purposes these are taken as one centimetre, one gramme, and one second, respectively.

There is one matter that has not explicitly been taken into consideration in thus defining the unit quantity of electricity, viz., the medium in which the action between the two charges takes place. It is assumed, however, that this is air, or more strictly speaking, a vacuum.

The attraction or repulsion between two quantities of electricity is proportional to each, *i.e.*, is proportional to the product of the two quantities. It is also inversely proportional to the square of the distance between them, always of course supposing that the two quantities are collected at two points.

12. **Electromotive force, potential.***—"Whatever produces, or tends to produce, a transfer of electrification, is called *electromotive force.* Thus when two electrified conductors are connected by a wire, and when electrification is transferred along the wire from one to the other, the tendency to this transfer, which existed before the introduction of the wire, and which, when the wire is introduced, produces this transfer, is called the electromotive force from the one body to the other along the path marked out by the wire.

"The electromotive force from any point along a path drawn in air, to a certain point chosen as a point of reference, is called the *electric potential* at that point.

"In experimental work it is convenient to assume as a point of reference, some object in metallic connection with the earth, such as any part of the system of metal pipes conveying the gas or water of a town.

"It is often convenient to assume that the walls, floor, and ceiling of the room in which the experiments are carried on have conducting power sufficient to reduce the whole outer surface of the room to the same potential. This potential may then be taken for zero. When an instrument is enclosed in a metallic case the potential of the case may be assumed to be zero.

"If the potentials at different points of an uniform conductor

* Quoted from Maxwell's "Elementary Treatise on Electricity," p. 5.

are different there will be an electric current from the places of high to the places of low potential.

13. **Physical analogies.**—"The idea of electrical potential may be illustrated by comparing it with pressure in the theory of fluids and temperature in the theory of heat. If two vessels containing fluids are put into communication by means of a pipe, fluid will flow from the vessel in which the pressure is greater into that in which it is less till the pressure is equalised. This, however, will not necessarily be the case if one vessel is higher than the other, for gravity has a tendency to make the fluid pass from the higher to the lower vessel. Similarly when two electrified bodies are put into electric communication by means of a wire, electrification will be transferred from the body of higher potential to the body of lower potential. Again if two bodies at different temperatures are placed in thermal communication, either by actual contact or by radiation, heat will be transferred from the body at the higher temperature to the body at the lower temperature, till the temperature of the two bodies becomes equalised. The analogy between temperature and potential must not be assumed to extend to all parts of the phenomena of heat and electricity. To raise a body to a high temperature may melt or volatilize it, but to raise it to a high potential produces no physical effect whatever on it. Hence the only part of the phenomena of electricity and heat, which we may regard as analogous, is the condition of the transfer of heat or of electricity according as the temperature or the potential is higher in one body or in the other. With respect to the other analogy—that between potential and fluid pressure—we must remember that the only respect in which electricity resembles a fluid is that it is capable of flowing along conductors as a fluid flows in a pipe."

In terms of this analogy the electricity is compared to the fluid, while the pressure of the fluid at any point answers to the potential of the electricity at a corresponding point, the difference of pressure between two points causes the flow of fluid from one to the other, while similarly the electromotive force or difference of potential between two points causes the flow of electricity from one to the other.

The conception of electric potential is a very difficult one, and this is not the proper place for a discussion of it in all its bearings; enough has been said in the long quotation from Clerk

Maxwell to give some idea of the meaning of the word, but the student who wishes to obtain a thorough insight into it cannot do better than read Clerk Maxwell's "Elementary Treatise on Electricity," giving special attention to Chapter III., on "Electrical Work and Energy."

14. **Electrometers.**—The only thing that can be observed in connection with electricity at rest is a difference of potential. It is possible to measure the quantity of electricity driven through certain instruments, just in the way that a quantity of water driven through a water meter can be measured, and some of these instruments will be discussed in a later paragraph; but for the present we can only appreciate electrical charge by observing a difference of potential, and electroscopes and electrometers are instruments for showing or measuring differences of potential.

The gold leaf electroscope has been shortly referred to above. The divergence of the leaves of this instrument may be taken as an indication that the knob or disc, or way by which electricity enters the instrument, is at a different potential to the walls of the room, or to that of the metal cage that surrounds some forms of the instrument, but obviously without further observation it does not tell whether the potential is higher or lower, *i.e.*, more positive or more negative, and further tests must be made to discover this. Neither does it give us more than the roughest indication of the amount of difference of potential. In cases where there is a great difference of potential, and a delicate gold leaf electroscope is likely to be spoilt, rougher forms may be used, *e.g.*, leaves of thin aluminium or even pith balls suspended by linen threads may be used instead of the more delicate gold leaf.

If it is required to measure a difference of potential an *electrometer* must be used. There are many forms of these, most of which are due to the inventive genius of Lord Kelvin. Descriptions of the various forms will be found in most textbooks, such as for instance in S. P. Thompson's "Lessons in Electricity and Magnetism," or the article "Electrometer" in the last edition of the "Encyclopædia Britannica."

15. **Distribution of charge. Density.**—It has been observed that the whole of an electric charge resides on the surface of a charged conductor, and this has been proved by direct experiment in many ways. It is found that while the

distribution over a sphere is uniform, as might be expected from the symmetry of the figure, it is not so on conductors of other shapes. On these the charge per unit of surface, which is called the density, is greater the greater the curvature of the surface till at a sharp edge or a point the density becomes so great that at high potentials a discharge takes place. For this reason if a point is attached to a highly charged conductor a stream of charged particles of air is repelled from the point, giving rise to a wind setting from the point and rapidly discharging the conductor.

16. **Action of points.**—This action of points becomes of great importance in some electrical machines, and in some kinds of electrical treatment. In the first place the presence of a point on a charged conductor renders it difficult to keep a charge on the conductor, however well it may be insulated. But the same effect will occur if a point be presented to a charged conductor; for the charge, which we will suppose is positive, of the conductor acting inductively on the point will induce a negative charge at the point, the density of which will become so great that it will be discharged to the original conductor, neutralising its positive charge, and leaving the conductor which bears the point positively charged if it is insulated. It is by this means that the prime conductors of most electrical machines are charged from the excited plate or other movable part.

17. **Capacity.**—The quantity of electricity that is required to raise the potential of any conductor from zero to unity, all other conductors in the neighbourhood being kept at zero potential, is the measure of its *Capacity.*

As the charge resides only on the surface of a charged body, the capacity of a conductor is determined by the extent of its surface, and a body of a large surface has a larger capacity than a body of smaller surface.

When a conductor is said to have a given capacity, it must not be thought that the conductor can hold only a certain fixed charge, in the way in which a bottle can be said to hold only so much water, because the quantity of electricity that can be put into a conductor of a certain capacity depends upon the potential or pressure at which it is charged. A body of unit capacity holds unit quantity when charged to unit potential, and holds ten times as much when charged to ten times the

potential. On this account it is necessary to know both the capacity of a conductor, and the potential to which it has been charged, before forming any idea of the quantity of electricity which it contains. The capacity of a conductor may be compared to the capacity of an elastic bag. The amount of air or of water that can be forced into an elastic bag depends upon the pressure at which it is forced in, and provided the bag does not burst, it can be made to hold more and more by increasing the pressure at which it is charged.

The capacity of a conductor is increased by bringing near to it other conducting bodies, which are maintained at zero potential by being connected to earth, and it may be stated generally that the nearer the "earthed" conducting bodies are to a conductor the greater becomes the capacity of that conductor.

The importance of this point is well brought out by an example. The capacity of a sphere of ten centimetres radius suspended freely in space is ten units, but if another sphere of eleven centimetres radius be placed concentrically to it, so that the two spheres are separated one from another all round be one centimetre of air, and if the outer sphere be maintained at zero potential by connection to earth, then the capacity of the inner sphere is no longer ten, but 110 units, while if the radius of the outer sphere be reduced to ten and a half centimetres, the capacity of the inner one would become 210 units.*

18. **Condensers.**†—An apparatus consisting of two insulated conductors, each presenting a large surface to the other, with a small distance between them, is called a condenser, because when one conductor is connected to earth, a small electromotive force is able to charge the other with a much larger quantity of electricity than if it stood alone, *i.e.*, its capacity is increased by the proximity of the other conductor.

The simplest form of condenser consists of two metallic discs supported on insulating stems, and facing each other, the intervening non-conductor or *dielectric* being air. If, now, a different dielectric, as for example, a sheet of glass, be inserted instead of air, the capacity of the condenser will be found to be different,

* If a be the inner and b the outer sphere, then the capacity of a is given by the formula $\frac{ab}{b-a}$.

† Maxwell's "Elementary Treatise on Electricity," Chapter VIII.

and greater than before, thus the action across the dielectric depends on the nature of the dielectric.

Since a glass condenser has a higher capacity than an air condenser, glass is said to transmit induction better than air, or in other words, glass has a higher *dielectric constant* or *specific inductive capacity* than air.

19. **Leyden jar.**—The electrical condenser most often used in experiments on static electricity, is that known as the Leyden jar (fig. 2).

The ordinary form of this apparatus is a glass jar or bottle, coated inside and out with metal foil to within two or three inches of the top. Through the cork of the bottle a wire passes, terminating above in a knob, and below in a chain, to make metallic contact with the inner coating. To charge the jar, the

FIG. 2.—Leyden Jar.

outer coating is connected to earth, and so kept at zero potential, while the inner coating is connected with the conductor of an electrical machine. The charge given to the inner coating acts inductively upon the outer coating across the dielectric of the jar, which is thus able to retain its charge. It may be discharged by bringing a metallic conductor, which is in connection with the outer coating, near to the knob of the jar. A spark will occur, and the jar is discharged.

The capacity of a Leyden jar depends upon the area of the surfaces coated with tinfoil, and also from what has been said in § 17, upon the thinness of the glass of which it is made. If the glass be very thin, it may give way under the strain when charged to a high potential, and be broken to pieces.

The discharge phenomena of a Leyden jar presents many

points of interest, and will be found to have important applications in some forms of medical apparatus. Generally the discharge takes place by a series of oscillations, which may be compared to the movements of a piece of watch-spring, or of an elastic rod which has been bent aside and allowed to fly back into its original position. The watch-spring, under these circumstances, swings to and fro several times before coming to rest.

In the case of the Leyden jar discharge, it will be found that the rate or "frequency" of its oscillations can be varied by varying the electrical dimensions of the Leyden jar or condenser, and those of the circuit through which the discharge takes place.

The subject is beautifully dealt with in Oliver Lodge's "Modern Views of Electricity" (Macmillan & Co., London), and should be carefully studied.

20. **Current electricity. Contact electromotive force.**—Volta observed at the end of the eighteenth century, that when dissimilar metals, such as zinc and copper, were brought into contact in air, electrical separation took place, and a small difference of potential was set up between the metals, the zinc being positive to the copper, or at a higher potential. Under these circumstances this difference of potential does not efface itself by discharging across the junction of the two metals, as a difference of potential between two parts of a homogeneous conductor would do, because the electromotive force set up at the junction of the two metals could only discharge itself across the junction by a flow in the opposite direction to that in which it tends to cause a flow, but that is absurd. But if the two pieces of metal, while in contact, are immersed in some liquid that is capable of acting chemically on one of them, *e.g.*, dilute sulphuric acid, a complete "circuit" is formed, and the discharge can take place through the liquid, which undergoes decomposition thereby, and the difference of potential being continually renewed at the expense of the chemical energy caused by the action of the liquid upon the zinc plate, a continuous discharge takes place round the circuit in the following way:—

Positive electricity passes across the junction of copper and zinc, and then from the zinc across the liquid to the copper again. If the connection of copper to zinc be by a wire, as is usually the case, we may use the language of the two-fluid hypothesis, and look on the junction as a sort of pump driving positive electricity round the circuit, so that it passes from zinc

across the liquid, or electrolyte, to copper and back to the zinc again, along the metallic connection between it and the copper, thus making a true circuit.

Such an arrangement is called a voltaic cell, and but for disturbances, that will be more fully considered, it would give a continuous current, till either the zinc or the exciting liquid (called the *electrolyte*) was exhausted. The difference of potential in a cell, or its *electromotive force*, was formerly thought to be due to the contact electromotive force of the metals forming the poles of the cell, though in certain cases this might be slightly modified by the liquid used.

21. **Theory of Arrhenius.**—This view has recently been examined again in the light of the fresh evidence which has been brought forward; in particular by the work of Van 't Hoff and Arrhenius. From their researches it seems probable that among the causes of the electromotive force of a cell, the "contact E.M.F." of dissimilar metals occupies a minor place, while the phenomena occurring in the solution or electrolyte are of greater importance. The arguments in favour of this view may be found very clearly stated in McMillan's "Treatise on Electrometallurgy,"* from which the subjoined summary has been prepared, while those who wish to go more deeply into the matter should read "The Elements of Electrochemistry," by Max LeBlanc.†

Briefly stated, the steps in the line of reasoning are as follows:—

a. Solution pressure.—The tendency of a body to go into solution when placed in a solvent, may be called its solution pressure, and the different degrees of solubility presented by different salts, which are very varied, may be spoken of as differences in their solution pressures.

The solution pressure of any particular body is constant under any given set of conditions, but varies definitely with any definite change in these conditions.

b. Osmotic pressure.—When a soluble substance is placed in water it goes into solution, at first rapidly, but as the solution approaches saturation it dissolves more and more slowly. The dissolved molecules appear to exercise a pressure which opposes the solution pressure, and eventually a point of equilibrium is

* Griffin & Co., London, 1899.

† Macmillan & Co., London, 1896.

reached when the opposing pressure of the dissolved particles equals the solution pressure of the substance. This back pressure is known as osmotic pressure, and is susceptible of accurate measurement.

We may take as a concrete example, the behaviour of zinc sulphate and distilled water. At 20° C. fifty-three parts of zinc sulphate will dissolve in one hundred parts of water, that is to say, the solution pressure of the salt enables it to dissolve in the water to that extent. At 50° C. 66·9 parts will dissolve. At these temperatures the solution pressure of the zinc sulphate is balanced by the osmotic pressure of the solutions, when those proportions of the salt are present in solution in the water. If the warmer solution be cooled, the equilibrium will be disturbed, the osmotic pressure will become stronger than the solution pressure, and solid zinc sulphate will be deposited from the solution. Conversely, if the cooled solution be warmed, its osmotic pressure will be reduced, and more of the salt will go into solution.

22. **Ionisation.**—The whole class of compounds known as electrolytes, break up, or are *dissociated* when dissolved in water. Sodium chloride, for example, breaks up more or less completely into the two separate parts, Na (sodium) and Cl (chlorine). Hydrochloric acid dissociates into H and Cl, zinc sulphate into Zn and SO_4, and so on, each molecule forming two separate entities, which are known as ions. The ions carry definite charges of electricity, those of the metals carry positive charges, those of the non-metals (chlorine, acid radicals, and the like) carry negative charges. The ions, SO_4, Cl, H, Na, &c., do not manifest the chemical properties of their elements as ordinarily recognised. The difference is one of their electrical charges, and when the ions are deprived of their charges, the element reappears in its ordinary form. In the solution the ions are equally diffused, and the positive electricity of the one set exactly neutralises the negative electricity of the other set, so that the dissociation of a salt does not affect the apparent electrical condition of the solution.

23. **Electrolytic solution pressure.**—If these conceptions be applied to the case of metals immersed in solutions, it is found that they possess the property of passing into solution, and of forming ions. This special tendency of metals to dissolve with the formation of ions, is called their electrolytic solution

pressure, to distinguish it from the simpler solution pressure of salts. Just as osmotic pressure opposes solution pressure, so it opposes electrolytic solution pressure. In the case of a metal immersed in solutions of its own salts, the osmotic pressure of the ions of the metal already in solution tends, in proportion to their number, to prevent the passage of fresh ions of the same kind into solution.

The electrolytic solution pressures of different metals, that is to say, the tendency of different metals to become ionised when in contact with a liquid, varies very greatly for the different metals.

The formation of ions from a metal requires definite positive electrical charges, and if ions are formed when a metal is immersed in a liquid, they must exist in the solution without any balance of negatively charged ions, such as are formed when a salt like $NaCl$ or $ZnSO_4$ is dissolved. Consequently the liquid must acquire a positive charge, and as both kinds of electricity must be simultaneously developed whenever electrical energy comes into existence, the metal acquires an equal negative charge. Electrical equilibrium is thus maintained, but the tendency of the metal to continue forming positive ions is opposed.

It has been observed, experimentally, that certain metals become negatively charged when immersed in an electrolyte, while others acquire a positive charge. Those of the former class have an electrolytic solution pressure which is large, and have a strong tendency to form ions, and those of the latter class have an electrolytic solution pressure which is low, and with them ionisation does not take place, except with special electrolytes. Tables have been drawn up of metals arranged in order, according to their behaviour in this respect, and from the point of view of their action when used as the metals of a voltaic cell they may be divided into those whose electrolytic solution pressure is greater than that of hydrogen, and those others whose electrolytic solution pressure is less.

An abbreviation of such a table would be:—

Zinc.
Iron.
Lead.
Hydrogen.
Copper.
Silver.

Those metals whose electrolytic solution pressure is greater than that of hydrogen, are able to deprive hydrogen ions of their positive charges, and thus to displace hydrogen in an electrolytic cell. They are the metals which dissolve in acids with evolution of hydrogen gas.

24. **Voltaic cell.**—If the voltaic cell be now considered as an electrolyte, H_2SO_4, in which the two dissimilar metals, zinc and copper, are immersed, it will be seen that each will exert its own solution pressure, and will become negatively or positively charged. The zinc, by virtue of its high electrolytic solution pressure, tends to form positively charged zinc ions, and in doing so becomes negatively electrified. The copper has almost no tendency to become ionised, and acquires a positive charge.

On joining the two metals by a wire, an electrical system or

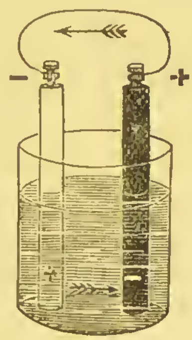


FIG. 3.—Voltaic cell showing direction of flow inside and outside.

circuit is formed. The copper communicates its positive charge through the wire to the zinc, and the zinc is thereby enabled to supply positive charges to its ions, which accordingly go into solution; the hydrogen of the electrolyte gives up its positive charges to the copper, and appears at the surface of the copper in the form of bubbles; the SO_4 ions remain unaffected. So long as zinc ions continue to go into solution, and hydrogen ions continue to give up their charges of positive electricity to the copper, the "current" of electricity flowing in the wire from copper to zinc will continue, but as the liquid becomes richer in zinc ions, their osmotic pressure will begin to oppose the electrolytic solution pressure of the zinc. Also, as the free available hydrogen ions diminish, through being expended, the renewal of the positive charge of the copper will begin to fail, and the action of the cell will fall off.

It is customary in some textbooks to speak of the zinc plate of a battery as the positive plate, and the copper or other plate as negative, while the terminal attached to the zinc plate is called the negative pole, and that attached to the copper the positive. The origin of this very confusing nomenclature is, no doubt, the fact that in the liquid the positive direction of flow of the current is from zinc to copper, and that zinc is said to be electropositive to copper. But in the connecting wire the positive direction of flow of the current is from copper to zinc (see fig. 3), and as this is the portion of the circuit that we are most concerned with, the word positive will be used to denote the positive pole of the battery, and also the plate connected with it, when it is necessary to specify this. This is in conformity with the usage of electrical engineers, who speak of the peroxide plates in an accumulator as "positives."

25. **Electrolysis.**—From what has been learnt in the preceding paragraphs, we can form the opinion that the solution of a salt in water leads to its dissociation into ions. This dissociation is incomplete except at stages of great dilution, but nevertheless we can regard such a solution as containing free ions, more or less abundantly. A solution containing free ions is called an electrolyte, and acts as a conductor, indeed the conductivity depends upon the presence of free ions, and a liquid conducts electricity well or badly in proportion to the degree to which it is dissociated, or (which is the same thing) to the number of free ions which exist in it. Water, for instance, conducts very badly when pure, and it has been calculated that its dissociation is very slight indeed.

The ions in an electrolyte, through which no current of electricity is passing, have no definite arrangement in the liquid so far as we know. Whatever motion there may be among them has no uniformity of direction, or at least has no tendency to any separation or sorting out of the positively and negatively charged ions.

If an electric current be produced in an electrolyte, as can be done by dipping into it two electrodes which are connected respectively to the positive and negative poles of a source of electricity, an orderly motion of the ions is brought about, and decomposition of the electrolyte takes place. The negatively charged ions will move towards the positive pole, and on reaching it they will give up their charges to the pole and lose their

existence as ions, and the positively charged ions will do the same at the negative pole. Thus with hydrochloric acid as the electrolyte, gaseous hydrogen and chlorine separate in unelectric form at the electrodes,* the hydrogen at the negative electrode or kathode, and the chlorine at the positive electrode or anode.

The course of events is, however, not always so simple as in the instance just given. Even in that case it would be necessary to employ as the anode of the cell, a metal whose electrolytic solution pressure was extremely small. Otherwise no chlorine would be liberated in the gaseous form, for the positive charges supplied to the anode from the external circuit would be expended, not in neutralising the negative charges of the chlorine ions, but in supplying positive charges to ions of the metal of the anode, which would accordingly enter the solution in the ionic condition, and would exist there side by side with the chlorine ions whose negative charges would thus be balanced by the positive charges of the newly formed metallic ions. In the case of an electrolyte of sulphate of copper with metallic copper electrodes, the passage of the current causes the copper ions in the electrolyte to move towards the kathode, and there to give up their charges and to appear as metallic copper, while at the anode, copper ions are formed at the expense of the copper electrode, and pass into the electrolyte; the effect, therefore, is the transport of copper from the anode to the kathode, and the latter gains while the former loses weight. The SO_4 ions associated with the copper in the electrolyte, migrate towards the positive pole, and as the action continues, they tend to become concentrated in that part of the solution.

If the electrolyte be a solution of a salt of an alkali metal, as for example sodium sulphate, and the electrodes be of platinum, the effects produced by the passage of a current again seem different, and this is on account of certain "secondary reactions." Suppose such a solution, to which some litmus has been added, be electrolysed, on the passage of the current gases will be evolved at both poles, and the litmus will show the presence of acidity at the anode and alkalinity at the kathode. The gas evolved at the kathode is hydrogen, that at the anode oxygen, and the explanation given, is as follows :—

The electrolyte contains free sodium ions and free SO_4 ions, also a few H and OH ions from the dissociation of the water,

† LeBlanc, "Electrochemistry," Chapter IV. "The Migration of the Ions."

which occurs only to a very slight extent. During the passage of the current the sodium ions migrate towards the kathode, part with their charges, and deposit sodium in the metallic form. Sodium, however, is decomposed by contact with water into sodium hydrate and hydrogen, accordingly hydrogen gas is evolved, and the liquid near the kathode becomes alkaline from the dissolved sodium hydrate. At the anode the SO_4 ions also lose their charges, and the SO_4 undergoes a secondary reaction with the molecules of water present to form H_2SO_4 (sulphuric acid) and oxygen, which is evolved. Objections have been raised to this explanation of the events, but it seems very likely that sodium is really set free in the form of metal at the kathode, because if mercury be used as the kathode, the evolution of hydrogen is decreased, and metallic sodium can be extracted from the mercury by suitable treatment.

The laws of electrolysis enunciated by Faraday* are as follows:—

a. The amount of chemical action is equal at all parts of a circuit. E.g., if several electrolytic cells, as they are often called, be arranged in a circuit, the amount of decomposition will be the same in each. If some of the electrolytic cells contain water and others contain sulphate of copper solution, the quantities of hydrogen or copper liberated will be proportional to their chemical equivalents.

b. The amount of any ion liberated in any given time is proportional to the strength of the current, and to the chemical equivalent of the ion.

The chemical equivalent for hydrogen is unity, therefore the weight of hydrogen liberated by one ampère running for one second, *i.e.*, by one coulomb of electricity, is the electrochemical equivalent of hydrogen. For any other ion the product of the weight liberated by one coulomb, multiplied by the chemica equivalent of the ion, is called the electrochemical equivalent of that ion. The electrochemical equivalent of silver is very nearly ·001118 grammes per coulomb, and the quantity of silver which one ampère would deposit in an hour is 4·0246 grammes.

26. **Heating effects of a current.**—A voltaic cell may be regarded as an apparatus by means of which the energy of the chemical action between the zinc and the electrolyte (§§ 22, 23), the ionisation of the zinc, can be in part converted into electrical energy and the process may be regarded as a combustion

* "Experimental Researches," Series V. and VII.

in which the fuel is the zinc. If a piece of zinc be simply dissolved in sulphuric acid in a test tube the energy liberated is wasted and serves only to warm the contents of the tube, but when the zinc is arranged in a voltaic cell some of the energy can be utilised in the form of an electrical current flowing through the circuit, and this current can be made to do work, or can be again converted into heat in any part of the external circuit of the cell. When an electrical current flows through a circuit, energy is absorbed by the resistance of the circuit and is dissipated in the form of heat, or in other words a wire carrying a current becomes heated by the passage of the current through it. The amount of heat generated depends (1) upon the resistance of the wire, being proportional to the resistance, and (2) upon the magnitude of the current, being proportional to the square of the current. Accordingly when it is wished to avoid the production of heat and the consequent loss of energy in a circuit, the conductors should be of low resistance (§ 27); and conversely when the current is to be used for the production of heat, as in the wire loop of a galvano-cautery instrument, or in the filament of an incandescent lamp, then the resistance of the part of the circuit which is to be heated must be made as high as may be necessary for the circumstances of the case and a relatively bad conductor must be chosen for that portion.

27. **Resistance.**—A current is set up in a conductor by electromotive force (§ 12), that is to say, there will be a current in a conductor if there be a difference of potential between its ends. It is soon found in working with currents, that with different conductors different currents are produced by the same electromotive force. There is therefore another factor that determines the magnitude of the current besides the electromotive force, and this factor is called the *resistance* of the circuit.

The resistance of a conductor is the inverse of its conductivity, and the conducting qualities of a body may quite well be expressed in terms of its resistance; thus the same idea is conveyed by saying that copper has a high conductivity or that it has a low resistance. It is customary and convenient to speak of the resistances of bodies rather than of their conductivities.

The resistance of a conductor depends upon the material of which it is made, and upon its length and its thickness. Thus a thick wire has a lower resistance than a thin wire of the same

length and material, and a short wire has a lower resistance than a long wire of the same thickness and material. This is expressed by saying that the resistance of a conductor is directly proportional to its length, and inversely so to its cross-section.

The electrical resistance of any material is a property peculiar to that material just as its hardness or colour or density is. Most metals are good conductors but they vary greatly among themselves in their electrical conductivity. Silver is the best conductor of electricity and copper comes near to it. Platinum has about six times the resistance of silver, and iron has a resistance slightly greater than that of platinum. As a general rule alloys have a higher resistance than the pure metals, German silver having about fourteen times the resistance of copper. Tables showing the relative conductivity of metals, and other bodies, are given in textbooks such as S. P. Thompson's "Lessons."

Tables of resistance are also made with the *specific resistances* of the materials tabulated. The specific resistance of a material is defined as the resistance of one cubic centimetre of the substance considered.

If the specific resistance of a substance is known, the resistance of any wire or rod of that substance can be calculated.

In general the resistance of metals increases with temperature. Some alloys have been made in which variations of temperature have very little effect upon the resistance, and these are of special value for the construction of standard resistances. That of carbon, however, decreases considerably. The carbon filament of an incandescent lamp has nearly twice the resistance cold that it possesses when hot.

Just in the same way as the resistance of a metal or other solid conductor is considered, so we may consider the resistance of a liquid or electrolyte.

The fact that electrolysis is taking place in an electrolyte does not prevent the consideration of its resistance in the same way as that of a non-electrolyte. Compared with metals the resistances of solutions are high, thus a salt solution may have a specific resistance upwards of a million times greater than that of copper.

As heat generally increases the resistance of metallic conductors, and decreases that of electrolytes, it is necessary to

take account of temperature whenever measurements of resistance are to be made.

The measurement of resistance in electrolytes may be complicated by electrochemical relations existing between the electrolyte and the poles of the electrolytic cell, and electromotive forces set up in the cell itself may obscure or vitiate the results if they are not properly recognised and guarded against.

28. **Ohm's law.**—The law showing the relation between electromotive force, resistance and current was enunciated by Dr. G. S. Ohm and is known as Ohm's law. It is as follows:—*The strength of the current in any circuit or part of a circuit varies directly as the electromotive force in that circuit and inversely as the resistance of the circuit.* This may be expressed in symbols thus:—

$$C = \frac{E}{R}.$$

Where C stands for the current, E for the electromotive force, and R for the resistance. From this formula we obtain in addition $E = CR$, or $R = \frac{E}{C}$. Thus we can calculate either C, E, or R if the values of the other two symbols are known or can be measured.

29. **Practical units.**—The electromagnetic units, as in the case of the electrostatic units, are all ultimately defined in terms of the units of mass, length, and time, and as in all electrical and other scientific calculations these are taken to be one gramme, one centimetre and one second respectively, the system of units is known as the absolute or centimetre-gramme-second (C.G.S.) system. It is found, however, that for practical calculation and use these units are not of a convenient size, *e.g.*, the units of electromotive force and of resistance are inconveniently small, and that of current is inconveniently large. The following system of units derived from these has therefore been adopted for practical use.

Electromotive force.—The practical unit is called the *Volt.* It is a little less than the electromotive force of one Daniell's cell (see § 37).

Resistance.—The practical unit of resistance is called an *Ohm.* The Paris Congress of Electricians in 1884 defined an unit of resistance to be called a "*legal Ohm.*" It is represented by the resistance of a column of pure mercury at 0° C., of an uniform

cross-section of one square millimetre, 106 centimetres long, and weighing 14·4521 grammes, it is slightly less than the true ohm.

Current.—The current which is given by an electromotive force of one volt acting through a resistance of one ohm is called one *Ampère.*

Quantity.—One ampère flowing for one second carries one *Coulomb* of electricity past any point in the circuit. Another unit of quantity much used by engineers is the quantity of electricity which would be carried by one ampère in an hour. This is called an *ampère-hour.* It is equal to 3600 coulombs.

Capacity (see § 17).—That capacity which would require one coulomb to charge it to one volt, is called one *Farad.*

These names commemorate the labours of Volta, G. S. Ohm, André Ampère, Coulomb, and Michael Faraday.

Even these units are inconveniently great or small at times, so certain prefixes are used to the names to denote multiples or sub-multiples of these quantities. Thus, a *megohm* is one million ohms, a *microvolt* is one-millionth of a volt, a *microfarad* is one-millionth of a farad, a *milliampère* is one-thousandth of an ampère; this last is the unit of current used in medicine.

The energy expended in a conductor may be calculated from the current in the conductor and the electromotive force acting upon it, the figure obtained by multiplying the electromotive force (in volts) by the current (in ampères) giving the rate of the expenditure of energy in terms of an unit known as a watt.

If E represents the electromotive force and C the current, then the watts W expended in the conductor are expressed by EC.

In any simple conductor the energy expended takes the form of heat. We are consequently able to calculate the rate at which heat is generated in the conductor; and if we know its specific heat and the rate at which it loses heat at its surface, we can calculate the temperature after the current has passed for any given time.

A watt is not a measure of work done, but of the rate of doing work. To obtain a measure of work done the time during which it goes on must be also considered. Thus one watt for one hour, or shortly, one *watt-hour* is a measure of work done.

By Ohm's law $E = RC$, and if in the equation $W = EC$, RC be substituted for E, we obtain the formula $W = C^2R$, for the rate

of doing work, for losses in a conductor, or for the heating effects of a current traversing a conductor.

The Board of Trade unit in which the energy sold to consumers by the Electric Light Companies is measured is one thousand watt-hours, and costs about sixpence.

This amount of energy can be made up in various ways; for example, taking the ordinary pressure of supply as 100 volts, ten ampères at that pressure for one hour, or one ampère for ten hours, alike represent the amount of energy of one unit. An ordinary incandescent lamp of sixteen candle power requires about sixty watts to keep it at a proper degree of brightness, and on a circuit of 100 volts it takes a current of ·6 of an ampère. Five of these lamps would use 300 watts, and if kept going for five hours the amount of energy absorbed would be fifteen hundred watt-hours, or one Board of Trade unit and a half, costing ninepence, if the price of the unit were sixpence.

30. **Thermoelectricity.**—In 1822 Seebeck discovered that a difference of potential could be produced by heating or cooling the point of junction of two dissimilar metals. If a rod of bismuth be soldered to one of antimony, and the free ends be connected by a wire, a current will flow through the circuit so formed if the junction of the bismuth and antimony be heated or cooled, and the current will continue to flow so long as the junction is maintained at a different temperature to the rest of the circuit. When the junction is heated the direction of flow is from bismuth to antimony through the heated part, but when it is cooled the current flows in the opposite direction. Other metals, and some alloys and minerals show the same effects. The electromotive forces set up are small, but by the combination of many couples thermoelectric batteries or thermopiles have been constructed for practical use. The opposite effect can also be observed. It was discovered by Peltier and is usually known as the "Peltier Effect." It is that if a current be driven through a thermoelectric junction the junction is cooled or heated according to the direction of the current. Thus a current passed from bismuth to antimony cools the junction and a current from antimony to bismuth heats it.

31. **Primary batteries.**—Numerous modifications of Volta's original cell have been proposed, from time to time, with the object of improving it, so as to obtain as high an electromotive force as possible, to diminish the internal resistance, and to secure con-

stancy of action. For medical work the most important point of all is to find a cell which will remain for a long time in good order without attention, and in which no wasteful chemical action goes on when the battery is not in use. On this account the Leclanché cell (§ 39) or some modification of it has almost entirely displaced the other types for medical purposes.

32. **Electromotive force of cells.**—The limit of electromotive force that can be obtained from a single cell is soon reached, since, as shown in § 23, it depends almost entirely on the electrolytic solution pressure of a metal, or substances. Tables are found in electrical textbooks of metals and other conducting bodies arranged in order, the most "electropositive" at the head of the table, the most "electronegative" at the foot. An abbreviation of such a table is the following :—

Electropositive.
Sodium.
Magnesium.
Zinc.
Iron.
Lead.
Copper.
Silver.
Mercury.
Platinum.
Carbon.
Lead peroxide.
Electronegative.

The similarity between this table and that given in § 23 is easily seen.

This order is given for the elements in the presence of dilute acid; under other circumstances the order is liable to some alteration, by reason of the influence which may be exerted by osmotic pressure and electrolytic solution pressure, under varying conditions.

It follows that the cell with the greatest electromotive force would be one, the poles of which consisted of the two materials at the extreme ends of the table, and many of the improvements in batteries made with the object of increasing the electromotive force have been by substituting bodies further down the list for the copper plate of Volta's cell. Thus in Smee's cell we find a platinized silver plate and in Grove's cell a platinum plate,

while in Bunsen's carbon is used. The best of these cells, when working properly, have an electromotive force of something under two volts. That of a Bunsen's cell is from 1·8 to 1·9 volts.

As will be seen in the description of secondary batteries, a positive plate of peroxide of lead affords a means of getting a high electromotive force, and the combination of it with a zinc negative plate has been suggested under the name of the zinc-lithanode battery, and has an electromotive force of 2·5 volts per cell.

If several cells be coupled together in series, that is to say, with the negative pole of the first joined to the positive pole of the second, and so on, the electromotive force of the combination measured from the positive pole of the first to the negative of the last cell, will be equal to the sum of the electromotive forces of the cells taken separately, thus, when high electromotive forces are required, the arrangement of a sufficient number of cells in series provides a means of obtaining it. If ten cells of an electromotive force of 1·5 volts apiece be arranged in series, the electromotive force of the whole battery will be fifteen volts. In medical treatment an electromotive force of 30 or 40 volts may be required; and a medical battery is, therefore, provided with a suitable number of cells connected together in series to give such a voltage.

33. **Internal resistance of cells.**—This is determined by the nature of the fluid in the cell, by the distance between the plates, and by the area of the plates. The internal resistance is low if the plates be large and close together, and high if the plates be far apart or small. If the whole circuit of a cell be considered, and divided into two parts, the external circuit in the wire, and the internal inside the cell itself, then a comparison of the resistances of the two parts will show what proportion of the total electrical energy of the battery is available for use in the external circuit, and what proportion is expended uselessly inside the cell itself; for example, in the case of a cell having an internal resistance of three ohms, and connected through an external resistance of six ohms, the energy expended in the outside circuit will be two-thirds, and that expended inside the cell will be one-third of the total. If the electromotive force of the cell be 1·5 volt, then one-third of the total fall or slope of potential (or ·5 volt), will be used up in

the cell, and the remaining two-thirds (or 1 volt) will represent the working electromotive force of the cell available for the outside circuit.

If the external resistance be 997 ohms, and the electromotive force and internal resistance be as before, then the electromotive force acting upon the external circuit will be very nearly the same as the full voltage of the cell; actually it will be in the ratio of 997 to 1,000 or 1·495 volt.

Thus one sees that in certain cases the internal resistance of a cell is an important factor in determining its value as a source of current, while in other cases it is insignificant. In working with the large resistances of the human body, the internal resistance of the cells composing the battery is an unimportant matter, as it forms only a small fraction of the total resistance of the circuit, and the waste or loss of electromotive force inside the cells is, therefore, a small fraction also.

In working with low external resistances, as in cautery work, and to a less degree in the illumination of parts of the body by incandescent lamps, the internal resistance of the cells becomes important, and special forms of cell with low internal resistances are designed for such work. Cells which have a low internal resistance are much more easily run down by short circuiting than are those with a high internal resistance. Accumulators with their very low resistances need special care in this respect, for if short circuited they may discharge at a relatively enormous rate, and be not only run down, but also seriously injured thereby.

34. **Arrangement of cells.**—The arrangement of cells in series has already been alluded to, and is represented in figure 4.

FIG. 4.—Six cells arranged in series.

Cells may also be arranged in parallel (fig. 5), that is to say, two

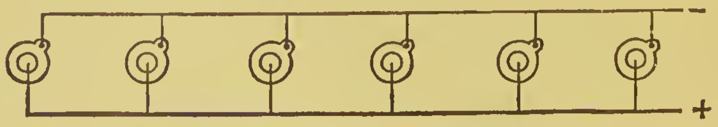


FIG. 5.—Six cells arranged in parallel.

or more cells may have their positive poles connected together

to form one pole of the battery, and their negative poles in like manner to form the negative pole. When cells are connected in series, the electromotive force of the battery is the sum of the electromotive forces of the cells composing it; the internal resistance of the battery is also the sum of the internal resistances of the cells. When similar cells are connected in parallel, the electromotive force of the combination is no more than the electromotive force of one of its components; but its internal resistance is diminished in proportion to the number of cells coupled together. With six cells in parallel thè internal resistance is one-sixth of that of one cell. It is sometimes useful to couple up the cells, which are at hand, in the best manner for obtaining the desired result, as the following example will show:—

Suppose the resistance of a cautery is ·1 ohm, and the cells to hand are of 1·6 volts each and ·5 ohm internal resistance, and suppose that the cautery requires eight ampères to heat it. If ten cells are coupled up in series we shall indeed get an electromotive force of sixteen volts acting through a resistance of 5·1 ohms, and this will give a current of a little over 3·1 ampères, but if they are coupled in parallel, the battery resistance will be only ·05 ohm, and the total resistance will be but ·15 ohm in the whole circuit. True the electromotive force will be only 1·6 volts, but by Ohm's law the current in this case will be 10·6 ampères. In the former case the cautery would not be heated, in the latter we should have enough current, and to spare. Conversely, it is of no use to arrange batteries in parallel when a current has to be passed through a high resistance, such as the human body, a resistance of at least 1,000 ohms, compared with which the internal resistance of thirty or forty cells in series is small. The coupling of cells in parallel has now lost most of its importance by the introduction of accumulator cells, whose internal resistance is so small as to be a negligeable quantity in medical work.

35. **Polarisation.**—Much attention and ingenuity have been concentrated upon securing constancy of current, and absence of polarisation in batteries. This is easily seen to be an important matter, for nearly all batteries undergo a rapid fall of electromotive force when any large current is taken from them. Thus, for example, a form of cell recently put upon the market had an electromotive force of 1·508 volts on open circuit, but after being

short circuited through a wire of low resisiance for fifteen minutes, the electromotive force had fallen to ·433 volt. Polarisation of a cell is mainly caused by alterations at the surfaces of the plates of the cell, and chiefly by the accumulation of hydrogen on the positive plate, which reduces the available electromotive force of the cell by substituting hydrogen, whose solution pressure is relatively high, for copper or carbon, in both of which it is low.

There are other causes which tend to produce a falling off in the current that a cell can give, particularly the exhaustion of hydrogen ions of the exciting fluid, or the saturation of the latter with zinc ions, if it be not renewed from time to time.

To prevent polarisation it is necessary to take some measures that will oppose the accumulation of hydrogen on the positive plate.

36. **Depolarisers.**—Depolarising methods can be conveniently grouped under three heads:—(*a*). Mechanical methods. (*b*). Chemical depolarisers. (*c*). Depolarisers.

In Smee's battery the surface of the silver plate is roughened by being platinised, *i.e.*, covered with finely divided platinum, the effect of which is that the bubbles of hydrogen are able to form and escape more easily. When a carbon plate is used its rough surface plays the same part, but it probably acts chemically also by causing oxidation of the hydrogen in the same way that the carbon of charcoal filters causes the oxidation of the organic matter of impure water. Another mechanical method of hindering polarisation is to keep the exciting fluid well stirred by forcing air through it or otherwise. None of these methods, however, are so efficacious as the use of chemical means, that is to say the use of some oxidising agent in the cell whereby the hydrogen is consumed, instead of being deposited on the positive plate. The simplest method of doing this is to add to the exciting liquid some compound that will oxidise the hydrogen as fast as it is liberated. This is the plan followed in the "bichromate" battery (§ 41) invented by Poggendorf. The chemical action of the depolariser upon the hydrogen reinforces the electromotive force of the couple. Another liquid depolariser that is used is strong nitric acid, but as this attacks zinc violently it is necessary to separate it from the zinc plate, where it would also be unnecessary, by the use of a semi-permeable porous partition or porous pot, which keeps it in the neighbour-

hood of the positive plate, where its action is needed, and the battery then becomes a two-fluid battery. In figure 6 the arrangement of a two-fluid battery is shown; V is the porous pot containing one liquid and one plate, the other liquid and the other plate standing outside it.

There are several solid depolarisers in use, the one best known being peroxide of manganese, which is used in the Leclanché cell. Oxide of copper is also used. Fused chloride of silver is the depolariser in a battery known as the chloride of silver cell.

37. **Daniell's battery.**—The oldest and most constant form of two-fluid battery is that known as Daniell's cell. So constant is this cell that it has been proposed and frequently used as a standard of electromotive force. For rough purposes we may

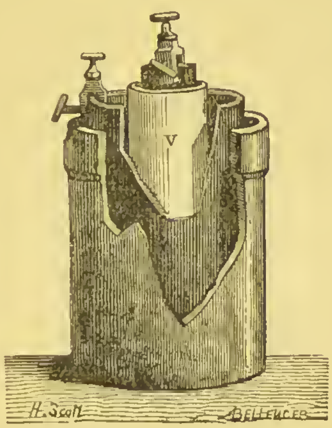


FIG. 6.—Two-fluid cell.

take the electromotive force of a Daniell's cell at 1·1 volt. A Daniell's cell consists of copper placed in a solution of sulphate of copper, which is kept saturated by having a few crystals of copper sulphate on a shelf near the top of the liquid, and, separated by the porous partition is a zinc plate in solution of sulphate of zinc slightly acidified with sulphuric acid. Frequently the copper is so shaped as to serve as the containing vessel. The porous partition, while it prevents the mixing of the two solutions, offers but little resistance to the electrolytic passage of the current. The reactions then are as follows:—Zinc ions go into solution at the zinc plate, and copper ions go out of solution at the copper plate. Since this latter is already of copper there is no tendency to polarisation here at all, and so

long as the copper sulphate solution is unexhausted there will be no falling off in the electromotive force of the cell, unless from the accumulation of zinc ions opposing the solution of the zinc by osmotic pressure. Daniell's cells might be useful in medical practice for charging accumulators.

38. **Other types of cell.**—Groves' and Bunsen's batteries have for their depolariser strong nitric acid. In the former the positive pole is a platinum plate, in the latter a plate or rod of hard gas carbon. In both batteries the positive pole is contained in a porous pot filled with strong nitric acid, and this is surrounded by the zinc plate contained in a vessel filled with dilute sulphuric acid. The fumes and the corrosiveness of nitric acid form the greatest objection to the use of this battery. It must be taken to pieces and cleaned every time it is

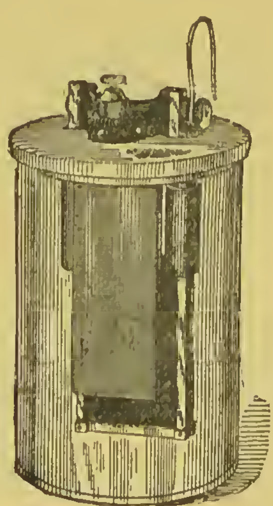


FIG. 7.—Edison-Lalande cell.

used. If it can be set up in a draught cupboard or an outhouse it can be used for recharging accumulators, but the process is a disagreeable one.

The chloride of silver cell was invented in 1868 by Warren de la Rue and Hugo Müller, and modified and improved by Skrivanoff in 1883. The depolariser is silver chloride fused round a silver wire which forms the positive pole of the cell. It possesses some good qualities, but it is a rather expensive cell to buy. Unfortunately the silver chloride passes into solution after a time, and is reduced to metallic silver on the surface of the zinc. Local action then sets in, and the cell deteriorates.

An American firm which claims to have overcome these difficulties manufactures a very neat form of this cell.

The Lalande oxide of copper cell, as modified by Edison, consists of plates of zinc and copper ; oxide of copper compressed upon the copper plate acts as a depolariser ; caustic soda solution is the exciting fluid (fig. 7). The cells are very constant, and can furnish large currents. There is little or no local action. Their electromotive force is low, ·8 of a volt, and they are not suitable for a portable battery, but might have an use in remote places for cautery work or for charging accumulators. They can be had from the General Electric Co. in several sizes.

The sulphate of mercury cell consists of plates of zinc and carbon in a solution of sulphate of mercury. It has been used for medical purposes in the pocket induction coils sold by M. Gaiffe, of Paris. In them two small cells are supplied in the form of little ebonite trays with carbon plates at the bottom; on these is placed a small quantity of the commercial sulphate of mercury, and a little water; the zinc plates are then laid on this and are kept from contact with the carbon by three vulcanite studs. The electromotive force is about 1·45 volts per cell.

Latimer Clark's standard cell is a form of sulphate of mercury cell, which is used in laboratory experiments, but it requires the utmost delicacy in management, and is used solely as a standard for the comparison of electromotive forces; its electromotive force is 1·434 volts at 15° C.

39. **The Leclanché cell.**—The cell most universally used for medical work is the Leclanché battery (fig. 8), the exciting solution in which is a saturated solution of ammonium chloride (sal ammoniac). The electrodes are a zinc rod and a carbon plate. The latter is surrounded by the depolariser (manganese dioxide), which is able slowly to oxidise the hydrogen evolved by the action of the cell. In the usual forms of Leclanché cell the carbon pole is in a porous pot, and is packed round with fragments of carbon and of granular manganese dioxide. Another form of cell has no porous pot, and thus its internal resistance is somewhat reduced, and the carbon has attached to it a conglomerate formed of manganese dioxide and carbon pressed into blocks. This form is called the agglomerate type. In another useful type the carbon and manganese dioxide are enclosed in a canvas bag with a cylinder of zinc outside.

When the circuit is open there is no action between the solu-

tion and the zinc; but when the circuit is closed the zinc is dissolved, while ammonia and hydrogen are evolved at the carbon pole. If only a small current is taken from these cells their action is fairly constant, but if much current is used, the oxidising action of the manganese dioxide is unable to keep pace with the evolution of hydrogen, and the cell becomes polarised, though it recovers again if left for some hours on open circuit. The electromotive force of a new Leclanché cell is about 1·5 volts. The advantages of the battery are that it possesses great powers of recovery, has no appreciable local action, and may consequently be left for months, or even years, at a time without attention, and has a fairly high electromotive force. Against

Fig. 8.—Leclanché cell.

these we must set the fact that its electromotive force runs down rapidly when it is called on to produce a current of any magnitude for more than a few minutes at a time.

None of the cells in which dilute acid is used for the exciting liquid can be left to themselves in the way that Leclanché batteries can, for in all of them the local action would soon destroy the zinc if it were not removed from the acid as soon as the battery was done with, and on that account alone acid cells are not suitable for medical purposes, since they require too much attention. Medical batteries must be carried to patients' houses when necessary, and open cells with acid liquids in them are not well suited for this. Even when the portability of the

battery is not important, the Leclanché element is still preferred, for once installed in a cellar or a cupboard it can be left alone without attention for years, and if large cells can be used instead of small ones, the capacity of the cell for doing work can be increased.

To preserve Leclanché cells in good order they must receive a little attention from time to time, about once in six months or so. The larger sizes in glass jars can be easily inspected, and the condition of the zincs and the level of the liquid ascertained.

If the zincs are blackened they should be scraped and amalgamated, and the liquid can be renewed by adding fresh solution of sal ammoniac. The cells must not be filled to more than two-thirds of their capacity, in order that the oxygen of the air may come into contact with parts of the carbon surfaces, and by being condensed there, may assist in depolarising. If the amount of work done by the battery has been large, and the solution has become milky, it had better be replaced by fresh. The proportion of six ounces of sal ammoniac to a pint of water makes a solution of proper strength. The upper inch of the glass cells ought to be brushed over with vaseline or hot paraffin wax to prevent *creeping* of the salts. This is the formation of crusts of the sal ammoniac around the top of the cell; it is harmful because it may lead to corrosion of connecting wires, so breaking the circuit.

When hard crystals form in masses at the bottom of the cell and round the zincs, it is time to take down the battery and to set it up afresh. If there is reason to think that the cells are worn out, the porous pots may be recharged with manganese dioxide and broken carbon, which can be bought ready mixed, or better still they can be replaced by new ones.

The management of the small Leclanché cells used in portable batteries is much more difficult, because it is impossible to see their condition; one can do little beyond emptying out the liquid with a fine syringe, and putting in fresh sal ammoniac solution in the same way from time to time. The most expensive part of the small medical Leclanché cell is its vulcanite case. In the dry cell this is dispensed with, and the latter are, therefore, cheaper.

40. **Dry cells.**—These are in many ways exceedingly convenient, and have come into general use for portable medical batteries. They are sealed cells of the Leclanché type, with a

pasty instead of a liquid exciting fluid. They will work in any position and require no special attention whatever, but it must be remembered that all sealed forms of cell have a capacity for work strictly limited by the original charge of chemicals, and cannot be restored to action, when run down, by the addition of fresh exciting fluid. In most of them the zinc plate is shaped like a canister, and forms the containing vessel of the cell, it is lined with a paste of exciting material, and inside this is the carbon and manganese dioxide. Cells of this type are made by the General Electric Co. (the E. C. C. cell), by Messrs. Siemens Bros. (the Obach cell and the Hellesen cell), and by numerous other makers.

FIG. 9.--Hellesen's dry cell.

These dry cells are made in several sizes, the smallest size for portable medical batteries weighs only eight ounces, and will last for a year with proper care, and after that time must be rejected. They cost eighteenpence apiece. The larger sizes are very good for working portable induction coils.

41. **The bichromate cell.**—This form of cell is still in use where large currents are required occasionally, and accumulators or electric light mains are not to be had. Its plates are of zinc and carbon, and the exciting liquid consists of a solution of potassium bichromate and sulphuric acid. Sodium bichromate has been recommended instead of the potassium salt, as the sodium salt contains, weight for weight, more chromic acid than the potassium salt. A suitable formula is the following:—Potassium bichromate or sodium bichromate, $6\frac{1}{4}$ ounces; water, 35 ounces; sulphuric acid, 6 ounces.

The zincs of this battery must always be removed from the solution immediately after use, and in fact should be well washed and frequently re-amalgamated, if the battery is to give the best effect. Bichromate cells are going out of use, and their place is being taken by accumulators for heavy work, and by dry cells in other cases.

42. **Accumulators or secondary batteries.**—A so-called *secondary battery* has this property, that when it is run down and exhausted it may be renewed by driving an electric current into it, and thus setting up an electrolysis that brings the plates and

FIG. 10.—Accumulator cell, showing arrangement of plates.

the electrolyte back to their former state, while in the *primary batteries* it is necessary to renew these. There is no more actual storage of electricity in these batteries than in a primary battery. Either may be looked upon as a store of energy, and in both, the energy stored is energy of chemical action. The lead secondary battery is the only one in actual use at present, both of the plates are of lead, placed in dilute sulphuric acid as the electrolyte ; these cells require "forming," that is, a current is passed through them for a certain time, and they are then allowed to discharge themselves through a resistance, they are then charged in the

opposite direction and allowed to discharge again, and this process is repeated several times. The object of this "forming" process is to increase their capacity by the production of a thick layer of lead peroxide upon one plate, and of spongy metallic lead upon the other. In practice, the plates are perforated grids of lead, and the holes in the positive plates are filled with a paste made of red lead and dilute sulphuric acid, which sets fairly hard in them. Those in the negative plates are similarly filled with a paste of litharge and sulphuric acid. The use of these oxides of lead in the composition of the plates, saves much time in the "forming" process. When a cell has just been charged it will be found, for a short time, to have an electromotive force of nearly 2·5 volts, but the working voltage is 2 volts. When the cells are discharging, the electromotive force is maintained at this point till about 75 per cent. of the charge is expended; after that the electromotive force falls quickly.

It may be taken as a general rule that as soon as the electromotive force of a cell falls below 2 volts, or 1·8 at the lowest, that cell should at once be recharged. If it is not attended to, sulphate of lead is liable to form on the surfaces of the plates, and this insoluble salt increases the internal resistance, and decreases the storage capacity of the cell until at last it may be ruined.

The internal resistance of a storage cell is almost infinitesimal when it is in good order, and may generally be neglected in calculations concerning them, at least in medical work. It is this low internal resistance which makes them so useful for cautery purposes, where large currents are needed.

The difficulties found in working with accumulators of the type having "pasted" plates, has caused some makers to return to the original type of accumulator as invented by Planté, where no pastes of the oxides of lead are used.

The Lithanode cell is a form of secondary cell which works well, and is made in several different sizes and in portable sets, some of which are admirably adapted for medical purposes, In the lithanode cells the positive plates consist of slabs of a very dense lead peroxide compound enclosed in a metallic framework, and they are free from some of the faults common to the "pasted" plates.

The Edison accumulator, which may prove of great value in the future, is a cell having for its active materials nickel per-

oxide and iron. The electrolyte is a solution of caustic potash. Both plates are of nickel-plated steel with numerous recesses or pockets to contain the active materials.

During the discharge of the cell the nickel peroxide changes to a lower oxide at the positive plate, and at the negative the metallic iron becomes oxidised. During charging the cycle is reversed and the changes may be represented as follows:—

$NiO_2 - KHO - Fe.$	$NiO - KHO - FeO.$
charged cell.	discharged cell.

The plates of the cell appear to act merely as conducting supports, and take no part in the chemical reactions, which are limited to the active materials.

The cells appear to behave remarkably well under trying conditions of all kinds. Irregular charging and discharging do not affect them so unfavourably as is the case with lead accumulators, and they may be left in a discharged condition for a time without injury. On this account they will probably be very suitable for the requirements of medical practice. The working electromotive force of the cell is 1·33 volts.

43. **The magnetic needle. Oersted's experiment.**—When a magnet is suspended freely at the surface of the earth, it is found that it swings so as to set itself with one pole pointing towards the North (or at least approximately so), and the other towards the South. The poles are spoken of as the *North seeking* and *South seeking* poles respectively, and their names are abbreviated into N. and S. for convenience.

Let a small magnet, say a compass needle, be suspended freely at rest. It will point North and South, now over it let there be carried a wire joining the two terminals of a Voltaic cell or battery in such a way that its course from copper to zinc along the wire shall be from South to North, *i.e.*, so that the current (the positive direction of flow) is from South to North, then the North seeking end of the magnet will be deflected towards the West. This observation is due to Oersted of Copenhagen, and it was formulated by Ampère into a law for telling the direction of flow in a circuit, thus:—Imagine a man swimming with the current in the wire, *i.e.*, from copper to zinc and facing the needle, the North seeking end of the magnet will always be deflected towards his left hand, whatever the position of the wire with regard to the magnetic needle.

44. **Magnetic field. Lines of force.**—The region of space about any magnet, and throughout which we consider its action is called its *field*, and lines of magnetic induction or lines of force round a magnet can be mapped out. These will then all start from points or surfaces indued with N magnetism and end in points or surfaces indued with S magnetism, and the intensity of a magnetic field at any point will be given by the number of lines of force which cross per unit of surface at right angles to them at that point.

It is easy to map the field of force round any magnet, since every magnet tends to set itself parallel to the lines of force at the point where it is. If then the magnet, whose field is to be mapped, be laid down on a sheet of white paper, and a small compass needle be moved about in its vicinity, the direction of

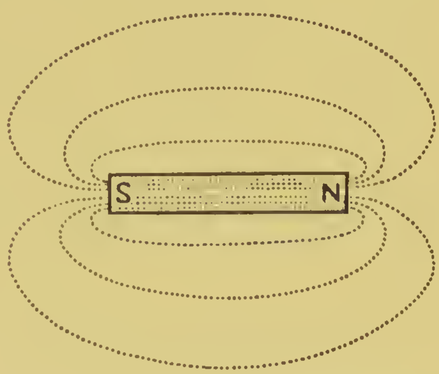


Fig. 11.—Lines of force of a bar magnet.

the needle at any point will give the direction of the lines of force at that point, and these can be plotted on the paper. And soft iron filings, in a magnetic field, become magnets themselves by induction, and so set themselves along the lines of force, mapping them out to the eye in a very beautiful manner.

If a sheet of paper be laid down over a bar magnet, and iron filings be sifted over the paper, and the paper be gently tapped, they will arrange themselves into a figure composed of curved lines which emerge from one pole, and pass round to converge at the other (see fig. 11).

45. **Field of force about a wire carrying a current.**—To return to the electric current. We can now draw a deduction from Oersted's experiment (§ 43), viz., that there must be a magnetic field of force about every wire that is carrying a

current, and since, when we are facing the magnet and swimming with the current, the N pole is always deflected to the left whatever the position of the magnet with regard to the wire, it follows that the lines of force must pass round the wire in circles, and it is easily shown that they do so by scattering iron filings on a card, through a hole in which a vertical wire carrying a moderately strong current is passed; when the card is tapped the filings instantly arrange themselves so as to map out the lines of force as circles round the wire; also if we look along the wire from copper to zinc, *i.e.*, with the current, the direction of the lines, the direction in which a N pole will move, is that of the hands of a clock. If a wire be bent into the arc of a circle, when a current passes through this arc there will be a field of force at the centre of the circle, due to the current at all points of the arc. If the arc were in the plane of the paper, and the current ran clock-wise in it, the direction of the lines of force would be vertically down from the paper.

46. **The electromagnet.**—To illustrate the magnetic properties of a wire carrying a current, many devices have been used from time to time as lecture experiments, and some have had important practical applications, as for instance, the electromagnet and the galvanometer. Soon after the discovery by Oersted of the effect of a current upon a magnetic needle, it was found that a wire coiled into a spiral or helix behaved as a magnet when a current traversed it, and the effect became very much more conspicuous if the helix were wound upon an iron rod or core.

In this way Sturgeon constructed magnets of great power, and gave them the name of electromagnets. Since his time electromagnets have had many useful applications, and as the field magnets of dynamo machines they now play a very important part in the industrial applications of electricity. For an account of electromagnets see "The Electro-magnet and Electro-magnetic Mechanisms," by Silvanus P. Thompson.

47. **Galvanometers.**—Oersted's discovery enables us to make an instrument for measuring the current in any circuit. Such an instrument is called a *galvanometer;* or when, as is sometimes the case, it is used merely to indicate the presence of a current, it may be called a *galvanoscope.*

In its simplest form the galvanometer consists of a coil of one or more turns of wire in a vertical plane, with a small magnet

suspended or supported freely at the centre. The needle being free to move, sets itself parallel to the magnetic field that happens to exist at the place where the galvanometer is to be used, and the coils of the instrument are then set parallel to the needle, and, therefore, to the magnetic field at the place. Hence the field, due to a current circulating in the coils, will be at right angles to the permanent field with which it is to be compared, and will tend to deflect the needle.

By multiplying the number of turns of wire in the galvanometer coils the action of the current on the needle becomes increased in proportion, each turn exercising its own effect. On this account the name of "multiplier" was once given to the galvanometer. But it must not be forgotten that if the number of windings be largely increased, *resistance* is thus introduced, which may have the effect of diminishing the current flowing through the coils. It is, therefore, necessary to wind galvanometer coils so as to suit the special purposes for which they are intended to be used. The galvanometers used for medical purposes are generally wound with several hundreds of turns. The resistance thus added to the circuit may be considerable, but as the resistance of the body is itself very high, the effect of the galvanometer resistance in diminishing the current is comparatively slight, and is quite unimportant as compared with the advantage gained by the multiplying effect of the turns of wire upon the needle. Thus the small currents used in medical treatment are enabled to produce large deflections of the galvanometer needle.

It must not be forgotten that the deflection of the needle of a galvanometer is not a direct measure of the current circulating in it. Galvanometers must be constructed to suit the special purposes for which they are intended, and some instruments will give considerable deflections with minute or even infinitesimal currents, while others require currents of comparatively huge magnitude to produce even a slight movement of the needle. On this account it is necessary, before comparing the deflections of one galvanometer with another, to be able to express their deflections in current, and galvanometers may be graduated by comparing them with standard instruments. In buying an instrument it is customary to specify the magnitudes of current which it is proposed to measure with the galvanometer required; the instrument maker is then able to provide a

suitable instrument, which has been already graduated to read directly into current.

48. **Measuring instruments.**—A galvanometer graduated to give readings in ampères is commonly known as an ampère meter or ammeter. The currents used for medical applications are usually measured in milliampères (§ 29), and the galvanometers used are called milliampère meters. Galvanometers can easily be graduated to give readings in volts, and are then called voltmeters. They are useful when it is wished to measure the electromotive force existing between two conductors at different potentials, as for example, between the poles of a voltaic cell or battery.

Many devices depending upon the magnetic properties of a wire carrying a current have been adapted for measuring purposes. Similarly the heating effects of a current, the electrolytic or chemical effects, and the effects of electrostatic attraction (§ 11), have been used in the construction of measuring instruments.

49. **Measurement of resistance.**—A galvanometer may be

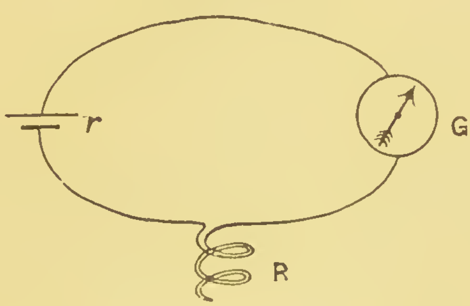


FIG. 12.—Measurement of resistance. *r*, battery. G, galvanometer. R, wire resistance.

used for calculating the resistance of a circuit or of a part of a circuit. Suppose a Daniell's cell of electromotive force 1·1 volts be connected up through a galvanometer, and the reading of the latter be ·05 of an ampère, then the resistance of the circuit will be by Ohm's law :—

$$R = \frac{E}{C} = \frac{1 \cdot 1}{\cdot 05} = 22 \text{ ohms.}$$

The resistance of 22 ohms will be made up of the resistances of the cell, of the conducting wires, and of the galvanometer coils. Now suppose a coil of wire, whose resistance is to be measured, be included in the circuit as in the figure, and the reading of

the galvanometer be taken again. Suppose it to be ·02 of an ampère, then by the same calculation, $R = \frac{1 \cdot 1}{\cdot 02} = 55$ ohms, the resistance of the circuit has been increased by 33 ohms, which is the resistance of the coil of wire which was to be measured.

50. **Resistance coils.**—The method of calculating resistances described in the preceding paragraph is often useful for rough determinations in medical work. In using it we have to rely upon the correctness of the galvanometer, and upon our knowledge of the electromotive force of the battery used. When exact measurements are needed another method is employed, by which these elements of uncertainty are avoided; and the resistance is measured by comparing it with that of standard "resistance coils." Permanent standard resistances are made from

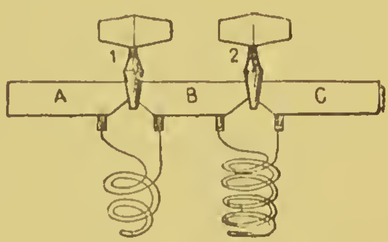


FIG. 13.—Plan of resistance coils.

lengths of wire specially wound into coils, and sets of these coils of suitable resistances are sold by instrument makers in a convenient form. The wires are made of German silver or of some other alloy, whose resistance does not change very much with changes of temperature. The coils are enclosed in a box

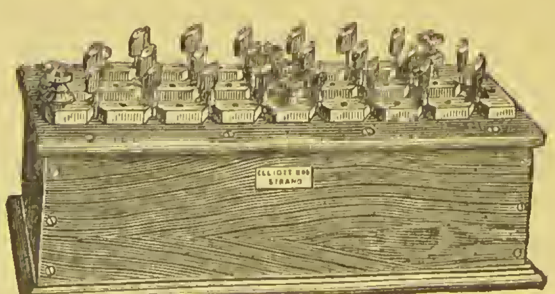


FIG. 14.—Resistance box.

for protection, and are connected to consecutive sections of a heavy brass conductor upon the outside of the box, as shown in figs. 13, 14. The plugs are used to cut out any of the coils which

are not to be included in the circuit. When a plug is inserted the current flows across the plug to the next section, and there is practically no resistance at that point. When a plug is withdrawn, the current must pass through the coil. The coils are arranged in the following order:—1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1,000, 2,000, 2,000, 5,000 ohms respectively. As any of them can be thrown in or out of circuit by removing or replacing plugs on the top of the resistance box, it will be seen that with the above arrangement of coils, any resistance from 1 to 10,000 ohms can be put into circuit. Such a resistance box can be used to measure resistances by what is called the "substitution method." A battery, a galvanometer, and the unknown resistance are connected together in circuit, and the deflection of the galvanometer is noted. A resistance box is then substituted for the unknown resistance, and the box is unplugged till the deflection has the same value as at first, when the resistance unplugged gives the value required.

51. **Wheatstone's bridge.**—The method generally used for

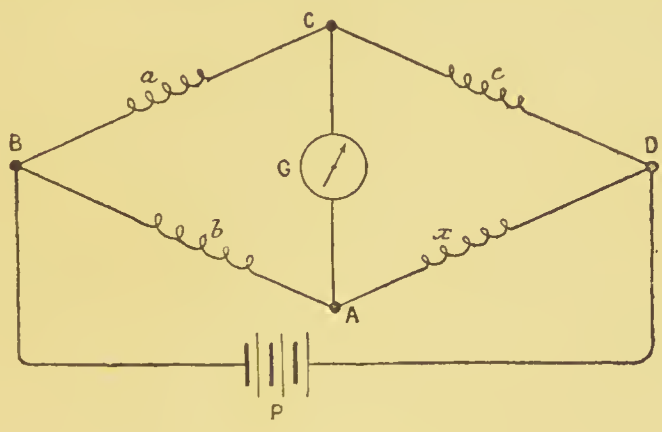


FIG. 15.—Wheatstone's bridge.

measuring resistances is called Wheatstone's bridge method, and consists of an arrangement of conductors as shown diagrammatically in fig. 15, in which P is a battery having its circuit divided along two channels at B, and reunited at D so that part of the current flows through A, and part through C. When the current is flowing thus, there is a gradual fall of potential along both wires, so that for every point along one, there is a point along the other which is at the same potential, and, therefore, a galvanometer attached to these corresponding

points would show no deflection, as there would be no current. If A and C are these points, and a b c x are the resistances of the various branches as drawn, when there is no current indicated by the galvanometer, we have the relation $a : b = c : x$, and if a, b and c are known, the fourth, x, can be calculated from this proportion. The resistance to be tested is joined in between A and D as shown at x in the diagram, and the resistance box is joined in between C and D. Then, as the simplest case, if the resistances at a and b are equal, the resistances at c can be changed by taking out or putting in the plugs of the box until a balance is obtained, and there is no current through the galvanometer. The sum of the resistances in the arm c is then equal to the resistance of the conductor to be measured. The Wheatstone's bridge method has been much studied and developed, and for details as to the use of the instrument, the various forms it takes, the precautions necessary in working with it, and for a description of the resistance coils, and the way they are wound and adapted, reference must be made to Kempe's "Handbook of Electrical Testing," or other modern textbook of electricity.

52. **Electromagnetic induction.**—When two distinct circuits are near to each other, currents in one will "induce" currents or, more correctly, electromotive forces in the other.

The induced currents are of momentary duration, and appear only when the inducing current is made to vary, as for example, when it is turned on or turned off. The current induced at the starting of the inducing current, is opposite in direction to the inducing current, and the current induced at the break of the inducing current has the same direction as the inducing current. This has been formulated by saying that the induced current is such that the field it would set up, tends to neutralise the change in field that is causing it (Lenz's law). These induced currents were discovered by Faraday, and on that account the induced currents employed in medicine are still known as "Faradic currents" among medical practitioners.

In § 45 it was stated that there is a magnetic field of force about every wire carrying a current, and the effects just referred to, depend upon the field of force surrounding the wire of the inducing circuit, and generally it may be said that every change of the magnetic condition of the space round a conducting circuit produces an induced E.M.F. or current in the circuit. Thus the increase or decrease of a current in the inducing

circuit, or the approach or withdrawal of the inducing circuit will change the magnetic conditions round the other circuit, which may be termed the "secondary" circuit, and will set up a current in it. Also for the same reason the approach or withdrawal of a magnetic pole will set up a current in a circuit during the periods of approach or withdrawal, and since the induced current depends upon the variation of the magnetic field in which the circuit is placed, it matters nothing whether the field is caused to vary by moving the magnet or the coil, or by making an unmaking a magnet by any means, or by varying a current in a neighbouring circuit.

The production of electric currents by electro-magnetic induction is of enormous practical importance. The commercial developments of electricity rest entirely upon the dynamo-machine, which is purely an apparatus for the generation of electricity by the induction effects of magnetic fields upon coils of wire. The importance of the dynamo-machine lies in the fact that it affords a means for the direct conversion of mechanical power into electrical power. It does this so simply and efficiently that the primary battery is becoming obsolete as a source of electrical energy, and survives to day only for special purposes.

53. **Induced electromotive force.**—It was stated at the commencement of § 52, that "currents in one circuit will induce currents, or more correctly, electromotive forces" in another. The meaning of the correction is that although the induction of currents implies the induction of electromotive forces, yet electromotive forces may exist without being able to give rise to currents. An electromotive force can only give rise to a current when there is a conducting path for the current. In the case of a circuit acting inductively upon a conductor near it, the latter would be the seat of a current if it formed part of a closed conducting circuit; but if it did not do so it would be the seat of an electromotive force only, as its circumstances would be against the production of a current in it.

In order to arrive at the magnitude of induced currents we must consider that by Ohm's law (§ 28) this depends upon two quantities, the electromotive force and the resistance of the wire. This latter is constant, since it depends only on the wire; the electromotive force alone varies. Its direction has been already considered, its magnitude is determined by the following law:—

The total induced electromotive force in any closed circuit is proportional to the rate of change of the number of magnetic lines of force through the space enclosed by the circuit. But the number of lines of force, or in other words, the strength of the magnetic field produced by a current in a circuit is proportional to the current in that circuit. Hence the law may run "*the induced electromotive force in any closed secondary circuit is proportional to the rate of change of current in the primary circuit.*"

54. **Self-induction.**—When a current is sent through a circuit, the magnetic field which is set up round the conductor reacts upon the conductor itself, just as we have seen it do upon a neighbouring circuit, and thus at the moment of completing a circuit the rise of current in it to its proper value is retarded by an induced electromotive force of opposite sign in the wire itself; while when the circuit is broken there is a momentary reinforcement of the current by an induced electromotive force of the same sign as that existing in the wire. This action of an increasing or decreasing current upon its own circuit is spoken of as an action of self-induction, and the reinforcement of the current at the break produced in this way can be amplified and made use of as will be seen later in the account of induction coils.

The effect which self-induction has of retarding the growth of a current in a wire is not of great importance in the case of steady currents because the effect is a transient one. In dealing with currents which are in a state of continual variation it is soon found that the matter may be one of very great importance. In the distribution of electrical energy by alternating currents, which is a very common form of electric supply, a consideration of the self-induction of the circuits is absolutely necessary if serious errors are to be avoided.

Conductors supplied with alternating current, especially when they are wound in the form of coils so as to set up strong magnetic fields, are found to have an apparent resistance which is very much greater than they have when tested by steady currents, and the introduction of an iron core into a coil of wire which is carrying an alternating current can easily be shown to produce a still further increase in its apparent resistance. From this it is clear that Ohm's law (§ 28) which specifies that the magnitude of a current in a circuit is determined by two factors only, viz., the electromotive force and the resistance needs to

be modified for the case of varying currents by the introduction into the calculation of a new factor, namely, the self-induction of the circuit. It is the opposing electromotive force, or *back E.M.F.* of self-induction which increases the apparent resistance.

Sometimes it is convenient to use the expression "ohmic resistance" to signify the resistance of a circuit as measured for steady currents and to distinguish it from the "virtual resistance" of the same circuit, when varying currents are being considered. The word impedance is generally used for virtual resistance.

It is very necessary for medical men to have some knowledge of the phenomena of electromagnetic induction, and of the behaviour of circuits carrying varying currents. Without an acquaintance with this part of the subject it is impossible to understand the induction coil, or the construction and management of the various forms of medical apparatus in which alternate currents are used. "High frequency" phenomena, too, can only be mastered by those who have studied the effects of self-induction and mutual induction. The preceding paragraphs may serve to indicate the importance of the matter, but for a proper elucidation of the laws of varying currents and of electromagnetic effects in general the reader must consult, and study, a modern textbook of electricity, as for instance, Silvanus Thompson's "Elementary Lessons," or Fleming's "Alternate Current Transformer."

55. **Alternating currents.**—The system of distribution of electrical energy by alternating currents is a very general one, and is in use in nearly a hundred towns and places in the British Islands. In a later chapter the utilisation of alternating electric lighting currents for medical purposes will be considered.

An alternating current is one which rises from zero to a maximum and falls away again to be followed immediately by a reversed current, which also grows to a maximum and wanes in the same manner. When a closed coil or circuit of wire is rotated in a magnetic field the wire is traversed by an alternating current of this kind once for every complete revolution of the coil, and this recurs again and again as often as the coil is rotated, giving one cycle or period for each revolution.

Each cycle consists of two semi-cycles which are equal and

opposite, the one corresponds to the passage of the coil through lines of N magnetism and the other to its passage through lines of S magnetism.

The changes in value of any varying quantity, as for example, electromotive force or current, can be represented graphically by a curved line, just as the variations in the body temperature of a patient are recorded upon the temperature charts used in clinical work.

If a horizontal line be drawn to represent periods of time, and if magnitudes of electromotive force be represented by distances above the base line (positive) or below it (negative) then an electromotive force gradually rising from zero to a maximum of fifteen volts positive, and falling again could be represented by

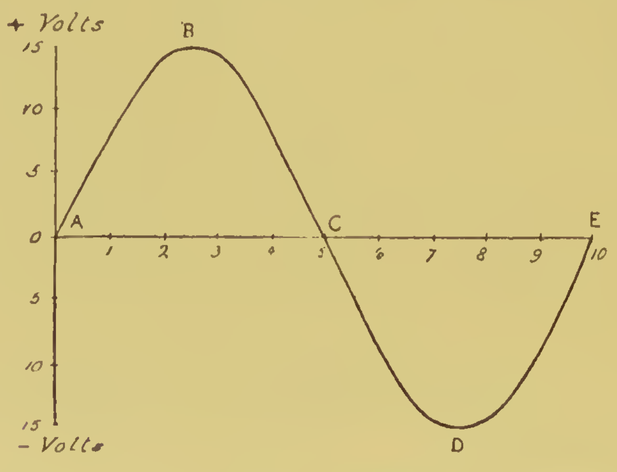


FIG. 16.—Graphic representation of a steadily varying electromotive force.

the curved line ABC (fig. 16), and the continuation of the curve CDE, represents a reversal in sign of the electromotive force, and a fall to fifteen volts negative, followed by a return to zero, the period of time of the whole cycle being represented by the base line AE. Similar curves could clearly be drawn to represent any values of a varying electromotive force or current and any periods of time.

When the shape of the curve is known the electromotive force at any instant can be readily determined by plotting out the curve, upon paper suitably ruled with lines (squared paper), and conversely curves can be constructed by observing a sufficient number of instantaneous values and marking them out on the paper and drawing a line to connect them.

The curve (fig. 16) represents the gradual rise and fall of the electromotive force from a properly constructed alternate current dynamo machine, and may be taken as approximating very closely to the kind of curve of the alternating system of electric light supply, and with such a curve the ratio of maximum current to mean current is as 1 to ·637, or as 1·57 to 1, if the mean be taken as unity. A curve of this kind is known as a simple periodic curve, or a sine curve, and the current from an alternating current dynamo is often spoken of as a *sinusoidal* current, to signify that it approximates in its wave form to a true sine curve.

The "frequency" of an alternating current or its "periodicity" means the number of periods or cycles occurring in one second.

56. **The dynamo machine.**—Commercial applications of electricity on a large scale would not be possible without the dynamo, because the primary battery, convenient as it is for some purposes, is altogether unequal to the work of producing electrical currents on a sufficiently large scale. Indeed there now are many applications of electricity in medical work which require currents of such magnitude that a dynamo or electric light mains are absolutely necessary for them.

In the future there will not only be a further increase of public supplies of electricity for illuminating purposes, but the advent of electrically driven motor cars to take the place of horse traction will probably lead to the setting up of private dynamo sets by medical practitioners in country places.

Already it may be said that motor cars are of use in diffusing electrical knowledge among medical men. The small accumulators which are widely used on motor cars for electric ignition, require care and study if things are to work smoothly; and the attention thus given to the management of accumulators serves as an introduction to the study of electricity in many quarters.

The motor-car accumulator once mastered, its employment for surgical galvano-cautery and lamp instruments is an easy step. In a later chapter these matters will be more fully dealt with.

In a dynamo there is a fixed magnetic part or "field magnet" and a moving system of conductors or "armature" which rotates in the magnetic field between the poles of the field magnet.

In the early days of dynamo-electric machines the field

magnet consisted of one or more permanent steel magnets. Instruments of this kind still survive, and under the name of "magneto-machines" have had a certain vogue for medical purposes. Otherwise electromagnets have now completely superseded permanent magnets for dynamos, and though the shapes seem to vary in different types of machines, all are essentially horseshoe magnets or groups of these.

The field magnet of a dynamo is an electromagnet magnetised or "excited" by the passage of a current through the coils of wire wound upon it, the current for the purpose being usually taken from the armature of the machine. A slight permanent magnetism exists in all field magnet cores and this is

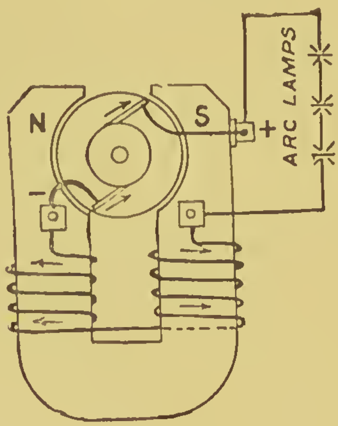


FIG. 17.—Series wound dynamo, with three lamps also in series in external circuit.

sufficient to start small currents in the armature when it is rotated. These currents are made to traverse the windings on the field magnet and they strengthen it so that it reacts more strongly on the armature until by the continuance of this mutual reaction between the armature and the field magnet the latter becomes fully magnetised. Thus a dynamo is a self-exciting machine. The armature is mounted on a shaft provided with a pulley for the purpose of rotation, and at one end of it is fixed the commutator, which is built up of a number of copper or brass segments insulated from the shaft and from each other; the ends of the coil or coils of wire which form the armature are connected to a pair of these commutator segments,

and when the armature is in rotation the segments pass in turn under the ends of two collecting brushes of metal which make contact with them.

The commutator is a necessary part of a continuous current dynamo, for it serves to rectify the alternate currents generated in the coils during their rotation and delivers them to the field magnet coils and to the outside circuit as a continuous current in one direction. In some dynamo machines the commutator is replaced by two insulated metal rings on the shaft. The collecting brushes touch these and collect an alternating current and such a dynamo is called an "alternator." Its field magnet must either be a permanent magnet, or else it must be excited from a separate source of "continuous" current.

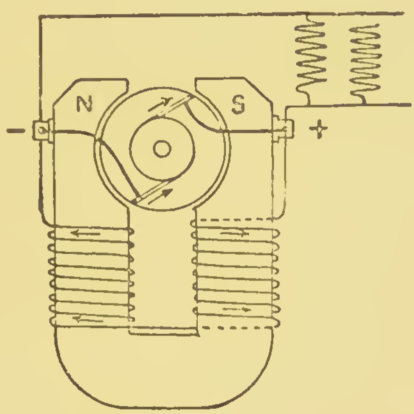


Fig. 18.—Shunt wound dynamo, with two resistances, also in shunt, in outer circuit.

When the whole of the current from the collecting brushes passes first through the field magnet coils and then through the outer circuit, the dynamo is said to be "series wound," the two portions of the circuit being in series, whereas a "shunt wound" dynamo has the field magnet coils in parallel or in "shunt" with the outer circuit (figs. 17 and 18). Each of these windings present advantages for certain purposes.

57. **Power for dynamo driving.**—Primary batteries are of no use for driving the large induction coils which are commonly employed for X ray work, and to use them indirectly for charging accumulators soon becomes tiresome. In the absence of

a public lighting supply a dynamo is almost a necessity, for without one the recharging can only be done by sending the accumulators to a dynamo station at a distance and the transportation of accumulators is expensive and troublesome and is by no means conducive to the long life of the cells. On the other hand it is rather a formidable undertaking for a medical man to set up a private dynamo for charging his accumulators, and especially so because it is difficult to procure a plant which is satisfactory without also being too big. One needs not only the dynamo, but also the power to drive it, and it is difficult to find good engines of very small power, as there is no great demand for them.

Manual power, windmills, water motors, hot air motors and gas and oil engines have all been applied to the driving of dynamos. In any particular case the local conditions will help to decide which is likely to be the most convenient source of power. In charging an accumulator from a dynamo, the electromotive force of the charging source must be maintained steadily above that of the cells to be charged, for if this is not done the cells will discharge back through the dynamo, with a result quite opposite to that desired. On this account manual power is apt to be too unsteady for charging purposes. By adapting a bicycle and so making use of pedal power, the Crypto Cycle Company of Clerkenwell have contrived a fairly useful apparatus for dynamo driving, and it is interesting to note that the electricity required for charging accumulators for Röntgen Ray work in the Soudan campaign was generated by means of an apparatus of this kind, a tandem bicycle being so converted as to drive the dynamo by means of a belt from the hind wheel. See the illustrated paper by Surgeon-Major Battersby in the *Archives of the Röntgen Ray* for February, 1899.

In some places a small windmill might be of use for charging a few storage cells, and where there is a cheap water supply a water motor gives little trouble, and would be a useful contrivance, but water motors consume much water. There are several forms of water motors in small sizes, which can be had from the makers of physical apparatus.

Many makers now list small gas engines of one-eighth or one quarter horse-power, which can be used to drive a dynamo for charging storage cells. These would probably answer for charging purposes quite well in the hands of anyone who was

willing to take a little trouble to get to know them thoroughly. The Pittler Company (144 High Holborn) list a "one man" power gas engine at nine guineas. In the larger size of one-half horse-power one begins to reach practical and good gas and oil engines. The Gardner Engines, for gas and oil, cost £15 and £25 respectively at this power, and can be specially provided with dynamo, pulleys, belts, &c., complete, for about ten pounds more. With one of these sets the charging of storage cells can be effectively dealt with.

When charging an accumulator from a dynamo the possibility of an unexpected stoppage of the machine must be borne in mind. To meet this possibility automatic switches have been contrived which at once cut off the cells from the dynamo circuit if anything goes wrong. This is necessary to prevent the charge already accumulated in the storage cells from running down through the dynamo circuit to the probable damage both of dynamo and cells. When the dynamo is running its polarity must be verified (§ 74) before joining up the cells to it. A shunt wound dynamo must be used for the purpose of accumulator charging.

58. **Motors.**—The direct current dynamo is a reversible machine inasmuch as it can act as a motor if supplied with current from an external source. In this case it converts an electrical current into power whereas when used as a dynamo it converts mechanical power into an electrical current.

Motors like dynamos may be either shunt wound or series wound. Motors have certain applications in medical work. In buying a motor it is necessary to specify the pressure of supply (in volts) from which it will be driven, the amount of power (in horse-power or fractions of a horse-power) it will be expected to exert, and in the case of alternating current circuits the periodicity of the alternations must also be mentioned. Motors for use on alternating circuits are more complex machines than are direct current motors. For an account of their construction, their advantages and disadvantages, special engineering text-books must be consulted.

The character of the electrical supply in the different electricity supply works in the United Kingdom will be found in the Appendix. There a list is given of towns having a public supply of direct or of alternating current with particulars of the pressure of supply and, in the case of alternating current, of the periodicity of the alternations.

CHAPTER III.

The Induction Coil. Medical Coils. Rhumkorff Coils. Motor-driven Interruptors. The Wehnelt Interruptor.

59. **The induction coil.**—One of the most interesting of the early observations in connection with electromagnetic induction was, that shocks and bright sparks could be produced from a single galvanic cell if its circuit contained spiral coils of wire. In § 54 it has been mentioned that these effects depend upon the self-induction of the circuit; and very shortly after the publication of the researches of Faraday and of Henry in 1831 and 1832, the subject was taken up by others, and coils were made by Page, Sturgeon, Callan, and others, which were the prototypes of the modern induction coil.

The peculiar physiological effect or shock which these induction coils produced soon led to their application to medical treatment, and in 1837 a machine contrived for this purpose by a Mr. Clark, was figured in Sturgeon's "Annals of Electricity."* Others quickly followed, and the drawings of the period commonly represent these coils as fitted with handles for patients to grasp, showing the general idea of the mode of employing them in therapeutics. By the introduction of the separate "secondary" coil, and of the automatic contact breaker, the induction coil acquired its modern form, and Duchenne commenced the study of the physiological effects of long and short coils, and of rapid and slow interruptors.

Since then the medical induction coil has undergone many modifications at the hands of ingenious instrument makers, but few of these modifications have been of much value, because the principles determining the physiological action of the coils have received but scant attention.

It is convenient to consider the phenomena of the induction coil as depending on the variations in the magnetic field of force (§ 26) of a coil of wire in which a current is continu-

* For a full and interesting account of the early history of the induction coil, see Fleming, "The Alternate Current Transformer."

ally being made and broken. The magnetic field set up in and around the coil at the moment of closing the battery current reacts upon the wire and produces in it a wave of opposing electromotive force which retards the growth of the current so that it does not instantaneously reach its full strength, and the collapse of the magnetic field at the moment of breaking the current also sets up a wave of electromotive force in the wire which strengthens the battery current and shows itself by a bright spark at the place where the circuit is broken.

In its simplest form an induction coil consists of a single coil of insulated wire wound upon a reel or bobbin with an iron core, and provided with an arrangement, usually a vibrating spring, for automatically closing and opening the circuit. It is connected to a voltaic battery whose current passes through the interruptor, and the current thus is periodically established and interrupted in the windings of the coil, and the magnetic field of the apparatus is caused to vary with every make and break of contact, and currents are induced in the wire coil. The induced current at break can be led off by properly arranged conductors and is the "primary current." It is distinct from the battery current. The primary current is therefore a series of impulses or waves, all passing in the same direction, and corresponding in time and frequency to the interruptions of the battery current; each wave is due to a sudden rise and fall of electromotive force in the wire, the whole time of each wave being a very small fraction of a second, and varying considerably in different coils.

The secondary current of an induction coil, as its name suggests, is derived from a second entirely independent coil wound upon the same bobbin as the primary coil. Being in the same magnetic field as the primary coil it is acted upon in the same way, but the effects produced in it are not quite the same. In the secondary coil there is an induced electromotive force corresponding to the rise of magnetism and an opposite electromotive force corresponding to its fall. Both of these can give rise to currents through an external circuit, and because they are in opposite directions the currents from the secondary coil are said to be alternating. They are not exactly alike in all respects, although the total flux of electricity is the same in each, for the electromotive force set up at the "make" of the battery current is lower, and the duration of the wave is longer, than at the

break, because, as has been seen, the rise of the magnetising current in the primary or inducing coil is more gradual than its fall.

The electromotive forces developed by induction in the

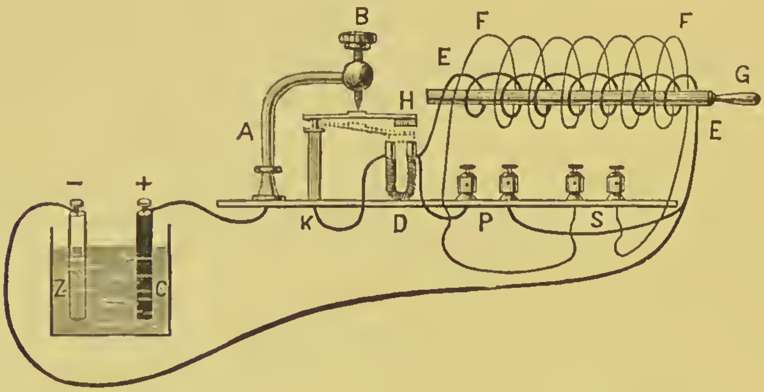


Fig. 19.—Arrangement of wires in an induction coil.

primary and secondary coils vary very much in different instruments. In both coils the electromotive forces reach maxima which are higher than that of the battery which supplies energy to the apparatus.

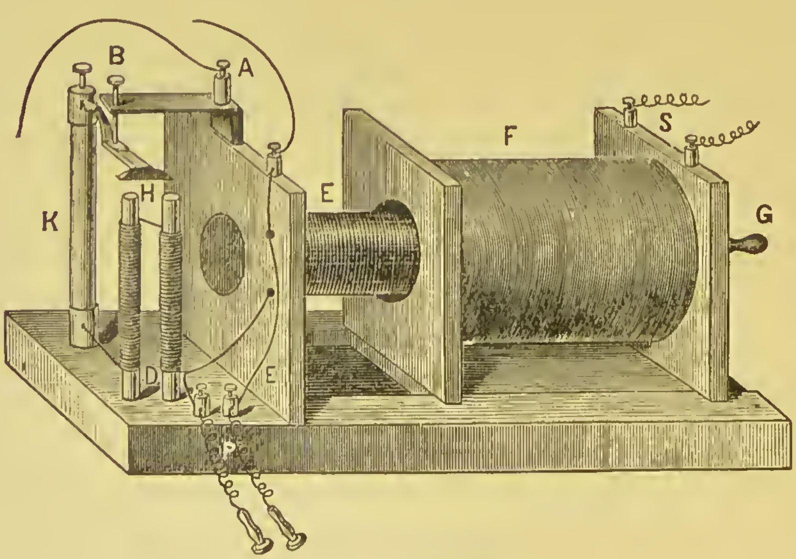


Fig. 20.—Induction coil.

Fig. 19 is a plan of the arrangement of the wires in an induction coil, and fig. 20 shows an actual coil. The lettering is the same in both of the figures. One pole of the battery is con-

nected to the binding screw A. The current then passes by the adjusting screw B, the vibrator H, and the support K, to a magnet D, which actuates the contact breaker. After traversing this the circuit gives off a branch to the binding screw P, and is continued to the primary coil EE, the return wire from which again gives off a branch to the second binding screw at P, and is then continued to the other pole of the battery. The two binding screws at P are thus in connection with the two ends of the primary coil, and by means of electrodes attached to them the patient may be treated with the primary current of this coil. The secondary coil F is wound on a separate hollow bobbin, and has its terminals at S. This bobbin is made to slide like a sledge on guides, so that it can be made to approach or recede from the primary coil. At G a handle is seen attached to the iron core which can slide in and out of the primary coil, and so further modify the electromotive forces induced in the primary and secondary coils, by varying the strength of their magnetic field.

The mode of action of the automatic vibrator or contact breaker is clearly shown in the figures. The electromagnet D, by attracting the iron armature H, draws down the spring and breaks the circuit at the point of the screw B, whereupon the attraction of the electromagnet ceases and the spring is released, and flying up, re-establishes the circuit; the action is then repeated, and the spring is kept in constant movement. By turning the screw B, the pressure upon the spring and its rate of vibration can be modified. Instead of the separate electromagnet, it is easy to utilise the magnetism of the iron core of the coil for working the contact breaker, and this is done in those patterns of medical coil which have a fixed core; but in that case some mode of regulation other than that of a sliding core is required.

In order that the coil may be used for medical purposes, there must be some method of regulating its strength. The following methods are in actual use in medical coils:—

1. By the use of a sliding core to vary the strength of the magnetic field.

2. By the use of a metal tube to slide over the iron core, and so shield the coils from its action by the effect of the tube as a closed conducting circuit.

3. By the use of a moveable secondary coil (sledge coil) which

can be brought into stronger or weaker parts of the magnetic field.

4. By a switch for progressively taking up into the circuit greater or lesser portions of the secondary coils.

5. By the use of a variable resistance for altering the strength of the battery current circulating in the primary coil.

6. By the use of a variable resistance in the circuit which connects the coil with the patient.

The variety of coils in the market is very great. Usually they are fitted up in a box with a battery to drive them, and with a drawer to hold wires and electrodes; this is convenient, as it makes them more portable. An inspection of an instrument maker's illustrated catalogue, or better still of his stock, is the quickest way of becoming familiar with the types of coil in general use.

In medical practice the induction coil has been universally adopted because it affords such a convenient means of producing marked sensory and motor effects at small cost. For purposes of stimulation it serves admirably, and in so far as electrical treatment consists of the simple stimulation of living tissues the induction coil is a most valuable appliance. Its use for accurate work, however, has the drawback that the measurement of induction coil currents is impossible in practice with any certainty.

Most of the methods proposed from time to time for measuring these currents are defective, partly because they do not take account of all the factors which are concerned in producing the physiological effects of an induction coil current, but also because of inherent defects in the construction of the apparatus. The difficulties, therefore, are partly physiological and partly physical, and the solution of the physiological problems will be delayed until the physical difficulties have been overcome.

The vibrating spring contact breaker of the induction coil is perhaps the weakest point of the apparatus, and its irregularities may cause abrupt changes in the strength and in the frequency of the coil currents; even during the course of a single operation the buzz of the vibrator can be heard to change its note, and with each such alteration it is possible to feel a change in the character of the current produced. In many coils this disagreeable effect is very marked. A change of this kind might indeed admit of measurement so far as mean electromotive force

or mean current was concerned; but here we find ourselves face to face with a physiological difficulty, which is, that the motor and sensory responses of living tissue to varying currents cannot be properly estimated from a knowledge of the mean current.

The physiological response is by no means proportional to the mean current or average current, but rather to the maximum current, and to the rate of change or its suddenness of rise and fall. It follows, therefore, that it is not enough to know the mean current or mean electromotive force of a coil unless the maxima and the rate of change can be arrived at. When the shape of the curve of a current is known the maxima can be calculated from the observed magnitudes of the mean current, but if the shape of the current curve is unknown or irregular then readings of mean current or mean electromotive force are not a sufficient indication of the physiological effect.

In the case of medical induction coils in general the shapes of their curves of current are both diversified and inconstant, and even for any single coil the determinations of its characteristics which might be made on one day could not be depended upon to recur unaltered on the next.

Certain points in the design of the medical induction coil quickly received attention, and the name of Duchenne will always be remembered for his careful investigations of the properties of medical induction coils. His researches, in the middle of the nineteenth century, remain as a monument to his industry and ability. His writings on the subject deal with the differences between the physiological actions of the primary and the secondary coils, the importance of the rate of interruptions, and the special effects of long and of short secondary coils. Very little has been added by later writers to that which was accomplished by Duchenne, and the words "faradism" and "faradisation" coined by him to signify medical induction currents persist to this day.

Some of the effects observed by Duchenne have hitherto remained unexplained, but they promise to become more clear when considered in the light of the effects of self induction upon the wave form and the duration of induction coil discharges.

60. **Differences between the primary and secondary currents.**—Duchenne summarises the differences between the currents of the primary and secondary coils by saying that the

primary current acts most strongly upon certain deep-seated organs as the testicle, the bladder and the rectum, and that it is to be preferred for the stimulation of superficial muscles as its action is more limited to the zone around the electrode, while the secondary coil on the other hand stimulates sensory nerves more powerfully, provokes reflex action more readily, and affects the retina more strongly when applied to the face near the region of the eye.

Of late years much has been made, especially in the United States, of differences in the windings of secondary coils, and some induction coils are fitted with six kinds of secondary windings which can be used either singly or in various combinations; but in spite of this instrument-making development we are still far from knowing enough of the physical effects resulting from such changes in length or thickness of secondary wire to be able to deduce the proper physiological consequences, or to lay down scientific directions for the proper construction of medical coils.

61. **Sledge coils and graduation.**—The methods of com-

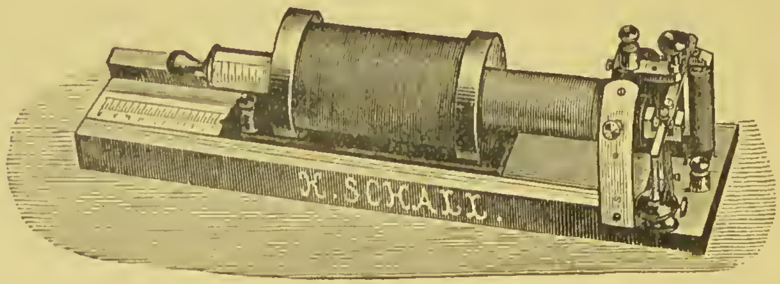


FIG. 21.—Sledge coil for medical use.

parison or measurement which have been proposed for use with medical coils deserve to be mentioned. The oldest is that proposed by Du Bois Reymond and still in general use in physiological laboratories in which the secondary wire is wound on a separate bobbin which can be moved to and fro along guides so as to bring it nearer to, or further from, the primary coil. A millimetre scale on one of the guides serves to mark the relative positions of the two coils, and the measurements are made in millimetres of distance. The method is useful when applied to identically wound coils which are identically excited, but variations in the action of the hammer are not taken into consideration, although these are of considerable importance.

Figure 21 shows a medical coil graduated on this principle and provided with a scale for registering the position of the secondary coil, and with a similar scale attached to the sliding core, for marking its position.

An useful addition to a sledge coil is the employment of a rack and pinion or a screw movement for changing the position of the secondary coil (see fig. 27).

Edelmann's faradimeter is a sledge coil in which the exciting current is maintained at a constant value by means of an adjustable resistance and a galvanometer in the battery circuit. The comparisons, however, still depend upon measurements of length in the distances apart of the primary and secondary coils. The increases of electromotive force in a secondary coil which is made to slide towards its primary are not simply proportional to the distances through which the coil is moved, and consequently equal distances do not represent equal increments of electromotive force. The scales are useful mainly in that they permit of the reproduction of approximately equal strengths of E.M.F. and current, and therefore they are useful for purposes of comparison in testing nerves and muscles.

62. **Measurement of induction currents.**—The measurement of the electromotive force and current due to induction in the primary coil is complicated by the presence in the circuit of the battery which drives the coil, and which exerts its own proper action upon any measuring instrument which may be put into the circuit. Reference to fig. 20 will show that the current induced in the primary circuit is led off by two branch wires which come from the two ends of the primary windings. The patient, therefore, is in shunt to the windings of the primary circuit when connected to the terminals at P, and a galvanometer connected up in his place would carry some of the battery current. The secondary coil, however, is an independent coil and the effects of induction in it can be measured, though not by an ordinary galvanometer. With such an instrument the alternate impulses from the coil tend to deflect the needle first in one direction and then in the other, with the result that the needle either remains quite still or else oscillates about its position of rest. If the magnetic needle be replaced by a small bundle of fine soft iron wires, these have no magnetic polarity and will be attracted by the coils of the instrument quite independently of the changes of direction of the current in the coils,

and by means of such a soft iron needle steady deflections are obtained, in spite of the rapid changes of direction of the currents of a secondary coil.

Mr. Giltay of Delft, Holland, has made an instrument* for use with medical coils. It depends in principle upon the attraction of a core of soft iron wires which are suspended between a pair of coils in a position at an angle of 45 degrees with their axis. When a current traverses the coils, the core tends to set

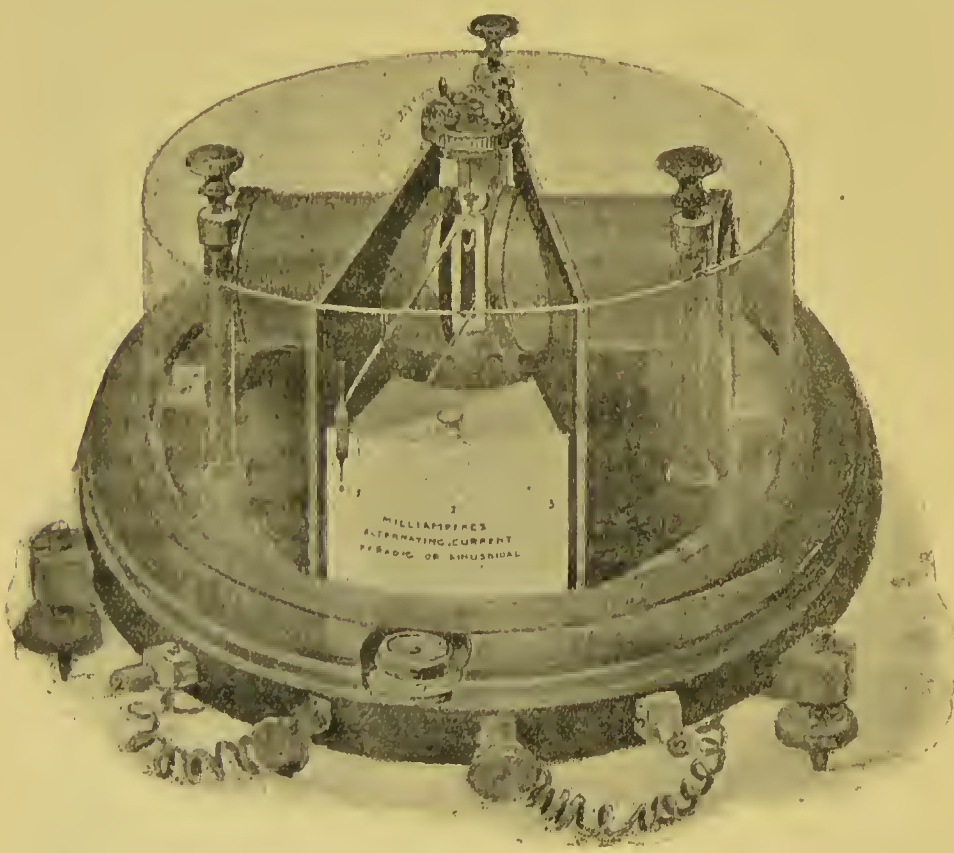


FIG. 22.—The Sloan faradimeter.

itself in the axis of the coils, and its movements are made visible by means of a scale and pointer.

Dr. S. Sloan of Glasgow has also designed a "Faradimeter" for the measurement of the currents of medical induction coils. His instrument is superior to that of Giltay in several respects, particularly in simplicity of management and in portability. The moving part in this case is not a bundle of soft iron wires,

* *Ann. der Physik und Chemie*, Bd. 50, Leipzig, 1893 (figure).

but is a suspended and freely moving coil of wire. An account of this instrument will be found in *The Journal of Physical Therapeutics*, vol. iii. The inventor gives an ingenious method of calibration, by which he claims to have succeeded in graduating his instrument to read in maximal current. For this to be so under all conditions seems hardly probable, though an approximation might be obtained for a given periodicity and duration of discharge.

The electromotive force of an induction coil can be best measured by an instrument invented by Lord Kelvin, and known as an electrostatic voltmeter. It is based upon the mutual attraction of two bodies oppositely electrified, and has the advantage of using no current, and therefore it measures the electromotive force of the coil on open circuit, subject to corrections for the capacity of the voltmeter. When the circuit of an induction coil is closed the voltage at its terminals falls away rapidly, particularly if it be closed through a low resistance.

A particular secondary coil was tested by means of an electrostatic voltmeter, and the potential difference at its terminals on open circuit was nearly ninety volts. When the circuit was closed through a resistance of 1000 ohms, in shunt to the voltmeter, the potential difference was only ten volts.

This observation shows the importance of measuring the electromotive force of a medical coil under conditions resembling those under which it is to be used.

63. **Current curves of coils.**—Many curves have been drawn from time to time on theoretical grounds to represent the discharges of induction coils, but actual tracings have also been taken, two of which are reproduced here from a paper by Dr. Kellogg* in which the method of doing so by means of an instrument devised by d'Arsonval is fully described. Dr. Kellogg's paper is a valuable contribution to our knowledge of the medical coil, and should be referred to by those who wish to study the subject.

Fig. 23 shows the discharge curves of a secondary coil when the battery current was made and broken slowly by hand. Here the wave at make is completed before the reverse current of break commences; the wave has a gradual and uniform

* "The International System of Electrotherapeutics," edited by Dr. Bigelow (F. A. Davis & Co., Philadelphia), 1894.

contour, both at the make and break, and a pause is seen between them. It can also be noticed that the wave at break rises to a higher electromotive force than that at make.

Fig. 24 shows a tracing taking with the vibrating interruptor of the coil in action. Here the curves are deformed, the make discharge commences as before, but the break discharge following too quickly after it, has altered the contour of the tracing,

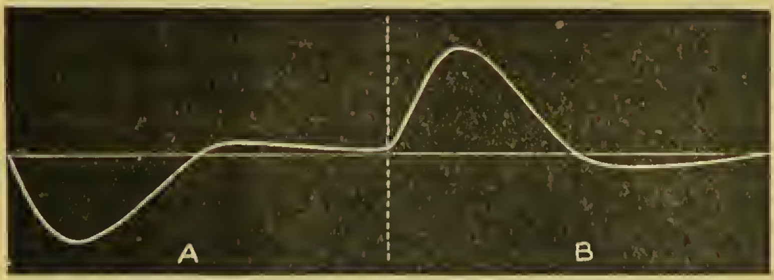


FIG. 23.—Secondary coil discharge. Battery current made and broken by hand. A. Wave at make. B. At break (Dr. Kellogg).

which now shows the break discharge as starting from the top of the wave of the make discharge, instead of from the line of zero potential. This means a reversal more or less abrupt of the direction of the current, and a change in physiological effect.

If some white blotting paper be treated with thin starch paste to which some iodide of potassium has been added, it can be used to investigate the discharges of an induction coil. The current is applied to the damp paper by two platinum points

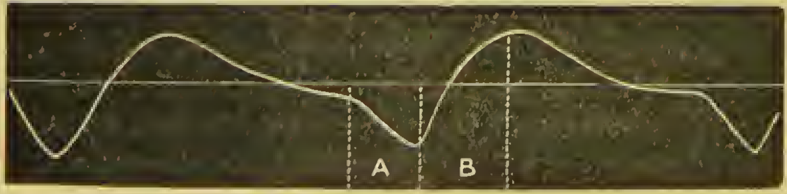


FIG. 24.—Secondary coil. Vibrator in action (Dr. Kellogg). Abrupt change from "make" A to "break" B.

fixed side by side as in the electrodes used by physiologists for demonstrating with muscle and nerve. By moving the points over the paper a double line of purple marks is traced, and if the speed of the movement is known the number of alternations of the current in a given time can be measured as well as the duration of the flow in each direction, because each mark means a period of positive flow from the point making the mark at the

time. With a regularly alternating current a regular double line of equally long dashes is produced, the marks of one line corresponding to the intervals of the other.

FIG. 25—Tracing of regular alternating current.

An induction coil current measured in this way was found to give long and equal discharges at each pole when the interruptor was moved slowly, but with rapid discharges it was found to give a tracing of altered character, one being short, and ending abruptly, the other being long and fading away gradually; and

FIG. 26.—Tracing of coil discharge—irregular.

further investigation showed that the discharge at break followed so quickly on the make discharge as to interfere with its regularity by terminating the former prematurely.

These traces, therefore, support those of Dr. Kellogg and tend to show that the secondary discharges of an induction coil may follow each other in such a manner as to interfere with one another and to produce a discharge of irregular character.

The extent of the interference of the two waves of current depends upon the character of the contact breaker, and varies in different coils. The more rigid the spring, the more likely it is that the rebound or break will follow too quickly upon the make. The shocks of an induction coil can often be very considerably altered in character by a little adjustment of the contact screw, because changes in its position may alter the play of the spring, and so make a difference in the way in which it rebounds after contact.

The more the problem of the medical coil is studied, the more complicated does it prove to be. By way of simplification of the matter, it may be stated that the "primary current" is unidirectional and consists of very brief discharges, while the secondary coil current is alternating in direction with its two semiphases unequal. The duration of the current flow of a secondary coil is longer than that of the primary, and this is true of both phases, and the greater the number of the secondary

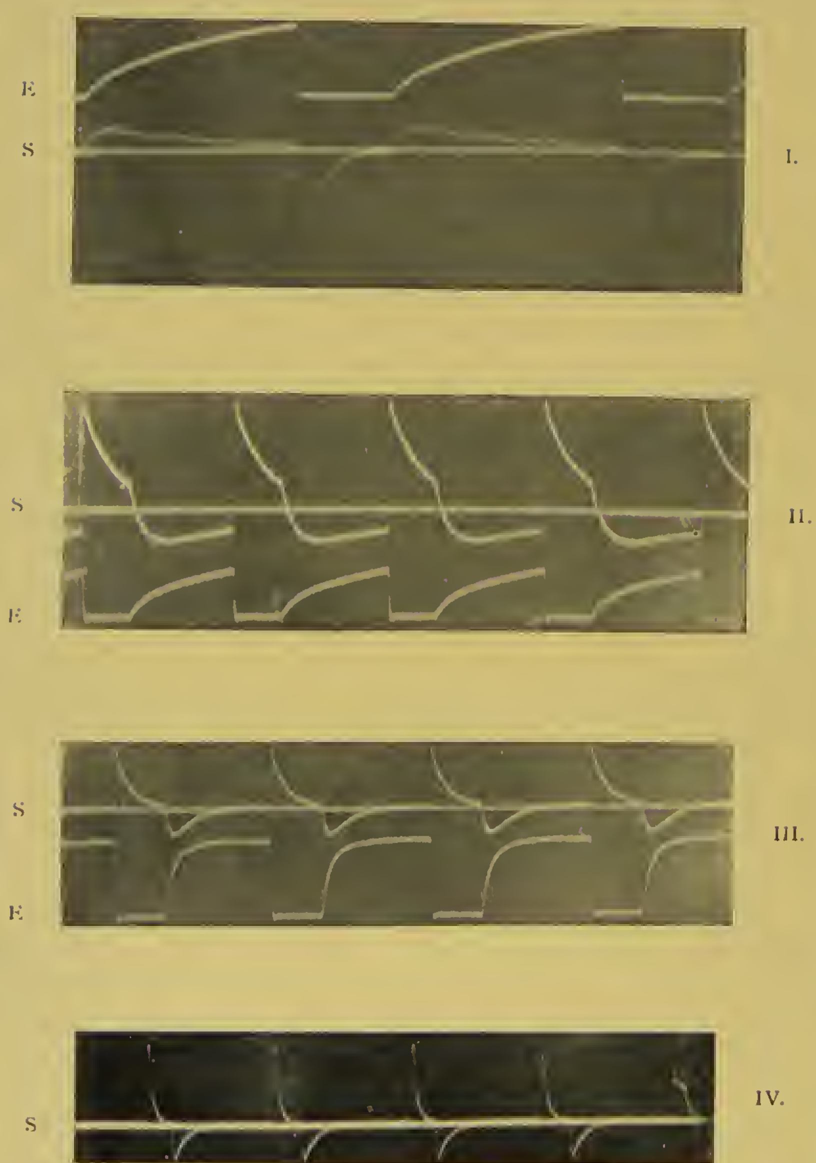
windings the slower will be the rise and fall of current, and the longer will be the total duration of the discharges. At a certain speed of the interruptor the make and the break are distinct from one another with intervals between them. At a more rapid speed the discharges will follow each other without any interval of no current between them, and with still more rapid interruptions the make and the break waves will interfere with each other. From this it follows that the curves of current of induction coils must vary very much in different instruments, and the physiological effects may depend as much upon the curves of current as upon the actual instantaneous values.

64. **Duration of current waves. Long and short coils.**— It may be asked why the alternating current of a dynamo is not used to take the place of the induction coil for testing purposes in order to escape the uncertainties of the induction coil, and the answer to this question is one of considerable interest. So far as measurement goes, the use of the sinusoidal current of the electric light mains for purposes of testing would be most convenient, but unfortunately it produces a burning or stinging effect upon the sensory nerves which interferes seriously with its use, and it is not impossible that this particular point may enable us to arrive at an explanation of some of the phenomena which have been known since the time of Duchenne, particularly of the fact that the current of the secondary coil has a greater effect upon sensory nerves than the current of the primary coil.

The duration of each discharge of an alternating current having a periodicity of 100, is one two-hundredth (·005) of a second, and that of the secondary of a coil may have a somewhat similar duration, for it has been measured in the case of a coil rather larger than those used in medical practice to have a duration nearly three times as long, ·0134 of a second.* It is well known that a long secondary winding produces greater sensory effects than a short one, and thus comparing together the short discharges of the primary coil with their lesser effect on sensory nerves, and the longer discharges of the secondary and of the sinusoidal current with their increase of painful effect, one arrives at the conclusion that long discharges may act more on sensory nerves in proportion to the muscular effect, than is the case with short discharges.

* "The Duration of the Discharges of Induction Coils," H. Lewis Jones, *Electrician*, July 21, 1893.

PLATE XII.



TRACINGS OF INDUCTION COIL DISCHARGES. TO BE READ FROM LEFT TO RIGHT.

I. Long secondary coil with iron core. Complete waves at slow rate of interruptor.
II. Long secondary coil with iron core. Incomplete waves at rapid rate of interruptor.
III. Same coil with core removed. Same rate of interruptor.
IV. Very short coil without iron core, giving very short waves.

E. Exciting current of coil, to show the effect of the iron core on the rate of growth of current.
S. Secondary discharges, corresponding with makes and breaks of the exciting circuit.

To face page 73].

In this connection it is interesting to note that recently in some experiments with a medical coil, it was found by Dr. Head that the removal of the iron core produced a marked effect in reducing the pain associated with electrical testing of muscles by that coil. An easy explanation of this is to be found if one considers the effect of iron in increasing the impedance of a circuit carrying a varying current, and thus of increasing the time occupied in the growth and decay of currents in such a circuit.

The tracings on the accompanying plate show the effect of the iron core upon the rate of growth of current in the exciting circuit of a coil, and the contours of the "make" and "break" discharges of the secondary, both with and without the iron core. They are taken with Duddell's oscillograph.

We may consider, in brief, that when impulses of short duration are wanted, the coil used should either be a secondary coil of few turns of wire, or better still the primary coil should be used instead of the secondary. If it were wished to shorten the duration of the impulses still more, the primary coil should have no iron core, and the interruptions should be produced by some mechanism which did not involve the use of an electromagnet in the exciting circuit. This must be taken as excluding the use of an auxiliary electromagnetic break, unless provision is made for it to be worked by an independent circuit which is not in series with the exciting circuit of the primary coil.

When impulses of long duration are wanted, as for instance, to produce strong sensory effects, the secondary coil, and especially the secondary coil of many turns of wire, is indicated. The high impedance of a long coil of many turns will prevent the currents from reaching high magnitudes, especially if the interruptor is a rapid one, and the available electromotive force of a long coil drops to a low value when closed through a resistance like that of the body, as was seen in the experiment referred to in § 62. Indeed the effective volts in a long secondary coil bear a relationship to the magnitude of the resistance of the external circuit to which it is applied, so that its behaviour may be compared to that of a cell or battery of high internal resistance, in which the available voltage or fall of potential in the external circuit is determined by the ratio between the resistances of the "internal" and external circuits respectively (see § 33).

Thus the long secondary coil is useful because it can develop

a high electromotive force when closed through a highly resisting external circuit, as for example, the dry surface of the skin, and in the opposite case, of applications to the mucous membranes where the resistance is low, the long coil gives a relatively low electromotive force, which almost automatically adapts itself to the altered conditions, and for this reason it comes about that the long coil is universally chosen for applications to internal parts, particularly in gynæcological practice.

A short secondary coil develops a low electromotive force, which is much less influenced by changes in the resistance of the external circuit, so that if this is high the current is a small one, but if it is low the current is proportionately large. Such a coil might appear to be very weak, if tested by its action upon the muscles through the imperfectly moistened epidermis, and yet, if applied without change in adjustment to the mucous membranes, it might give very severe or even injurious shocks.

With the electric bath, which has a low resistance, a secondary coil of 300 turns of wire was tried, and proved to produce a greater effect than a coil of 900 turns of the same wire which was compared with it.

Another way of expressing the difference between long and short coils is to say that the short coil gives a lower voltage but a larger current, while the long coil gives a high voltage and only a very small current; the larger current of the short coil is able to influence deep muscles because it is not so much reduced by diffusion through the tissues as in the case with the small current of a long coil. And, on the other hand, the small current of the long coil makes itself sharply felt at the point of entry through the skin, but is scattered by diffusion before reaching the deeper parts. The fine coil should be used with a wire brush electrode, or other electrode of small surface, as this concentrates the current at the points of contact, and produces effective stimulation there, with little or no effect upon parts which are further removed.

Most of the coils in common use have intermediate properties, because the number of their windings is neither very small nor very great, and they are therefore not so well suited for the special purpose of stimulating the sensory nerves of the skin or the mucous membranes, without affecting the deeper parts at the same time. Duchenne maintained that for the treatment of neuralgic pains the use of a current from a short coil

is injurious, because it produces muscular contraction in the affected parts, whereas the action should be limited to the surface, and patients will usually say that the pain of neuralgia is increased by the treatment if a short coil is used.

65. **Thick wire and thin wire coils.**—Long coils are nearly always wound with fine wire, and short coils with thick wire. The difference between a short coil of thick wire and a long coil of fine wire, depends very much more on the number of turns than on the diameter of the wire, for the ohmic resistance of the wire is only a small part of the total impedance of the coil. One secondary coil can, therefore, be made to take the place of two or more separate coils, if by any means the number of turns in actual use can be varied. This may be done by tapping the secondary coil in several places, and bringing out a wire from each of these places to a separate binding screw. Coils of this kind are made, in which one-third or two-thirds, or the whole number of the turns, can be used at will.

In the best instruments two separate and interchangeable secondary coils are provided, one of a smaller number of turns of wire, and one of a very large number of turns, so that either coil can be used as the case under treatment may require.

It is difficult to specify precisely what is the most suitable number of turns to give the short coil or long coil effects. In Duchenne's instruments the short coil had a length of 100 metres, and the long coil 1,000. These figures will suffice to indicate the general proportion between the two coils.

66. **Frequency of interruptions.**—The rate of vibration of the contact-breaker of the induction coil has received a good deal of attention, but still waits for careful analytical study. Coils are made with regulating devices for producing at will almost any rate within comparatively wide limits, as, for example, from one vibration to two hundred per second in Ewald's coil (fig. 27). In this the vibrator has the form of a pendulum C, swinging between two springs B and D. B can be altered in position by means of the screw A, and so controls the range of swing of the pendulum and influences its rate of vibration. "The singing rheotome," is an interruptor which vibrates so rapidly as to emit a high pitched note, estimated at 500 per second.

The average rate of vibration of the contact breaker in common use in medical coils is about fifty per second.

If the impulses are so infrequent that the muscle has time to relax between its successive contractions there is more commotion of the muscle, and greater discomfort than when it is maintained in a condition of tetanus. For producing tetanus a greater average strength is necessary with infrequent impulses. Some coils with heavy contact-breakers give disagreeable shocks through the slowness of their rate of interruption.

From 50 to 60 vibrations per second is a very suitable rate for testing and treatment; at speeds of 100 and upwards a peculiar benumbing effect makes itself felt round the electrode and if this should happen to be applied over a sensory or mixed nerve trunk, this numbness is felt over the whole area of distri-

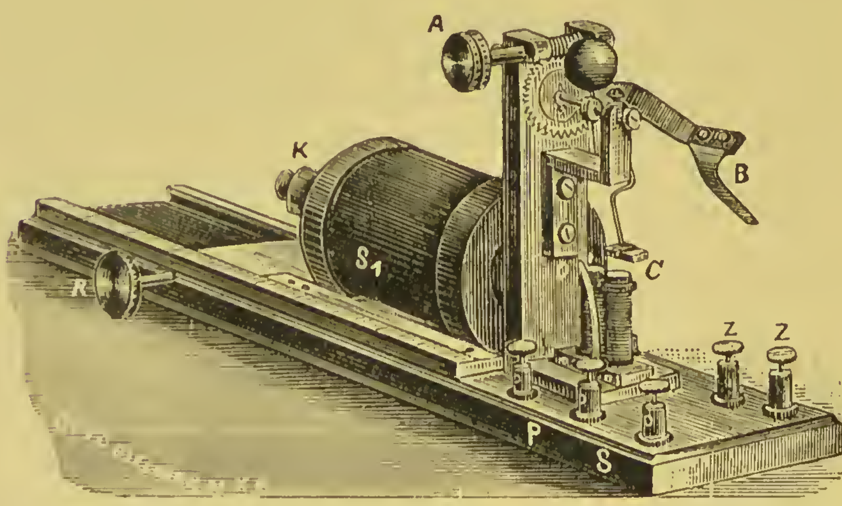


FIG. 27.—Ewald's coil. Z. Battery terminals. P S. Primary and secondary terminals. K. Core. R. Handle of rack and pinion movement for secondary coil, S_1.

bution of the nerve, and along that part of the nerve trunk which extends from the point stimulated to the periphery. The effect is peculiar, and enables one to feel, by experiment on one's self, the area of distribution of a cutaneous sensory nerve in a very instructive way.

Some of the more elaborate medical coils of the present day are fitted with contact breaking arrangements driven by electromotors, and others have a key for single shocks and two interruptors for different speeds, with a switch for throwing any one into circuit at will.

A coil whose contact breaker is vibrating rapidly shows a

decreased effect which is due to the fact that the exciting current has not time to rise to its full value before it is broken again, consequently the magnetisation of the core, and the induction in the secondary coil do not rise so high as they would if the same coil were worked at a lower speed. This can be met by increasing the electromotive force of the battery used to drive the coil.

Duchenne preferred a rapid vibrator for acting upon sensory nerves, and for certain conditions of muscular atrophy and for stimulating muscles when they would not respond to slow interruptions, or had lost the muscular sense; for general purposes of muscular stimulation he advised slow interruptions, and preferred them in treating muscles paralysed by cerebral lesions, because he considered that the slow stimuli were less likely to set up reflex irritation at the seat of the lesion in the skull. He believed that rapid interruptions might hasten the degeneration of muscle in certain cases. His slow interruptions were of the rate of one or two per second.

In a very valuable paper recently published by Leduc,* an account is given of an apparatus for examining the effect of rapidly interrupted currents upon muscular contraction. The apparatus consists of a revolving commutator driven by a small electric motor. By an ingenious arrangement of collecting brushes the circuit is closed for a certain fractional part only of each revolution of the commutator. With this apparatus the number of impulses per second can be varied by varying the speed of revolution of the motor, and their duration, that is to say, the period during which the circuit is closed in each revolution can be regulated by moving the position of one of the brushes. Working with this apparatus Leduc has found that for the rate of one hundred intermittences per second, the best physiological effect corresponds to durations of time of current flow of one-thousandth of a second, with nine-thousandths of interval, and any increase or decrease from these proportions of time of current flow requires an increase in the electromotive force needed to produce a minimal muscular contraction. With this apparatus the rise and fall of current is more brusque or sudden than with alternating currents from a dynamo or from an induction coil.

D'Arsonval has shown that for alternating currents the phe-

* *Archives d'électricité médicale*, September, 1903.

nomena of excitation of nerve and muscle increase with increase of frequency until the rate of 3,000 alternations per second is reached, that the effect then seems to remain stationary up to a rate of 5,000, and afterwards decreases progressively with any further increase in the frequency.

Much remains to be done before our knowledge of the influence of varying frequency of electrical impulses can be considered satisfactory. It is very probable that the sensory nerves may respond differently to vibrations of different frequencies. Heat radiations emitted by warm bodies have a rate of billions per second and yet they can easily be distinguished by the nerve endings from other forms of tactile sensation.

67. **Practical conclusions.**—The induction coil has been considered at some length in the preceding paragraphs because

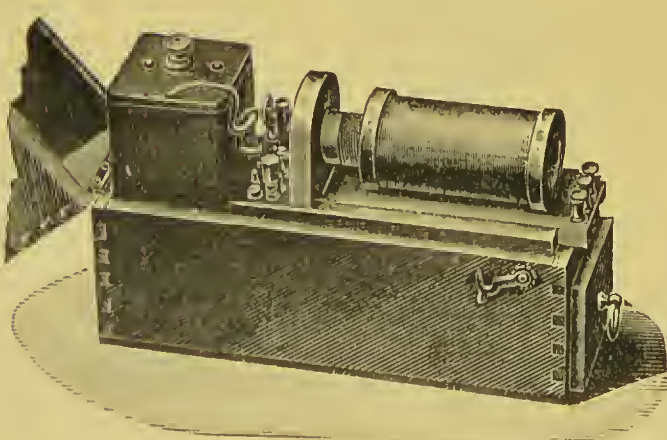


FIG. 28.—Portable sledge coil with subdivided secondary winding.

it is perhaps the most important electrical appliance in common medical use, and because the points which have been discussed are of value as a guide in the choice and in the use of the instrument.

In choosing an induction coil the points to be attended to are as follows:—

First, to see that the vibrator works smoothly. This is very important, as many coils are defective in this respect, and give an irregular series of shocks of unequal strength, which is unpleasant for the patient; before buying a coil it is a good plan to have it set in action, and to test it upon one's hand and cheek. In this way it is easy to learn whether it works evenly, and whether it permits of satisfactory regulation of its strength

within a sufficiently wide range. The coil should be quiet in action, and it should not require a large exciting current, or else the cell used to drive it will want frequent renewal.

There may be two different secondary coils, or else one which is tapped at several places, so that either a part or the whole of the turns may be utilised at will. Figure 28 shows a simple form of portable medical coil which answers these requirements, and has a secondary subdivided so that one-third of the windings form a short coil secondary, while the effects of a long coil can be had by using the whole of the windings.

Medical coils are not fitted with condensers, as larger induction coils are. It is probable that the addition of a condenser would improve them and would also tend to preserve the platinum contacts of the interruptor in good condition. This use of a condenser will be considered in the next section.

68. **Rhumkorff coils.**—Induction coils are used not only for direct medical applications, but also in the form of Rhumkorff coils of great power for the excitation of X ray tubes, for the generation of "high frequency" currents, and for the spark-discharge lamps which are used in the treatment of disease by ultra-violet light rays. It will, therefore, be useful to touch upon certain points in their construction and management. Rhumkorff coils are commonly classified in terms of the length of spark which they are capable of giving. Thus a ten inch coil is one which can give a spark ten inches long. Ten, twelve, and even eighteen inch coils are now in common use among medical men.

These large coils require to be manufactured with care, and with attention to detail in every part. The primary windings are of two or three layers of thick copper wire, for they have to carry currents of considerable magnitude without becoming heated. A plug arrangement is used in some modern coils for varying the self-induction of the primary circuit by connecting its layers in shunt or in series as may be desired to suit the voltage of the source from which it is driven. The core is made of a bundle of fine iron wires carefully annealed, to facilitate the magnetic changes which are to take place in them. A solid bar of iron would not do, because it would be a source of great loss of energy through becoming the seat of induced currents or "eddy" currents. The secondary coil is of fine wire

carefully covered with silk insulation, and ten or twelve miles or more may be required.

To secure a good and lasting insulation of the secondary coil is essential. The core is wrapped in varnished tape, and, after being wound with the primary wire, is usually enclosed in a thick vulcanite tube. On the latter the secondary wire is wound in sections. For smaller coils the secondary is wound in single layers along the length of the bobbin, like cotton on a reel; but in large coils it is best wound in sections, an arrangement which may be compared to a row of reels arranged side by side on a spindle, with the ends of cotton carried from one reel to the next.

A twelve inch coil may have seventy or eighty of these sec-

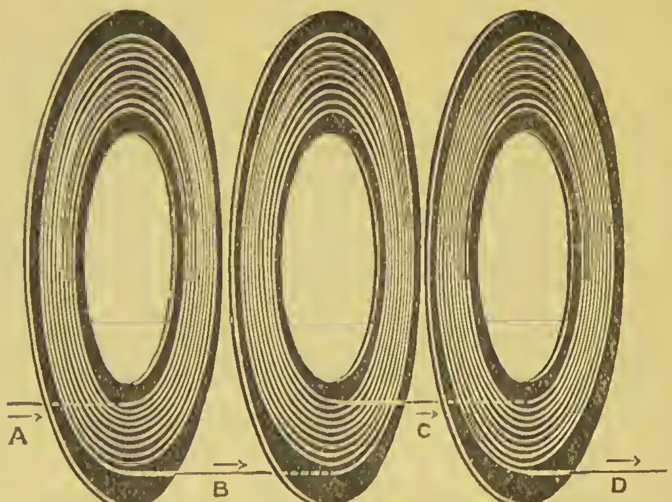


Fig. 29.—Plan of winding in the jointless section coils.

tions arranged side by side, and separated from one another by thin discs of ebonite.

The object of the sectional construction is to arrange the windings so that there shall not be any great difference of potential between contiguous portions of the secondary coil. The sectional construction has been developed to its highest degree in the "jointless section" coils of Mr. Miller. Under this patent, every single flat spire of winding has its corresponding insulating layer of waxed paper and the completed secondary may have from 700 to 1200 single layer sections. The extra care thus taken in the insulation of the secondary, serves to diminish very considerably the number of turns of wire

necessary for a given length of spark, and thus reduces the weight and bulk of the coil. It also reduces the resistance of the coil and its impedance, and the sparks of such a coil are consequently thicker, and the quantity of current in the discharges is increased. The output of a coil, though commonly estimated by its simple sparking distance in air, can be better estimated by observing the effect produced upon the length of spark when a capacity is connected to its secondary terminals. The reduction of spark length produced by the introduction of a Leyden jar, or of any other condenser of given capacity, is less the greater the magnitude of current in the discharges of the coil.

The appearance of the completed coil is well known.

In a box below the board on which the coil is mounted, and

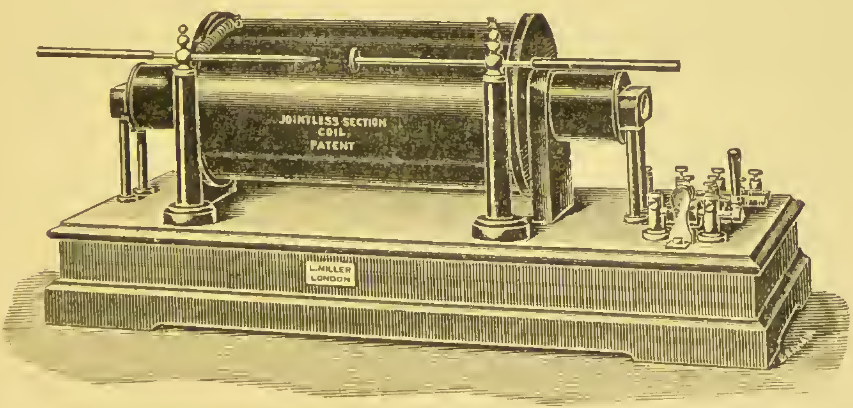


FIG. 30.—Modern Rhumkorff coil, without hammer.

forming part of the base of the instrument, is placed the condenser. This consists of a number of sheets of tinfoil, insulated from each other by sheets of paraffined paper. The metallic sheets are connected in two sets, the even numbers on one side being connected to one of the two supports of the contact breaker, and the odd numbers on the other side to the second support. The object of the condenser is to accelerate the rate of decay of the current in the primary circuit, as the efficiency of the coil depends upon the suddenness with which this is accomplished. When the current from the battery is broken, the heat and the spark at the platinum points tend to prolong the time during which current can pass, and make the interruption, to a certain extent, a gradual one. The condenser is of service by reducing the amount of sparking, for the electro-

motive force induced in the primary wire by the rupture of the circuit charges the condenser first, and from the condenser it discharges back through the primary windings, producing a momentary reverse current in the primary wire, and thereby favours the demagnetisation of the core. With very sudden interruptions the condenser ceases to be necessary.

At the side of the contact breaker is usually found a commutator switch for reversing the direction of the current in the primary circuit. It also serves for turning the current on and off.

69. **Interruptors.**—The contact breakers of large coils may either be of the ordinary vibrating hammer type, like those used in small medical induction coils, or the interruptions in the primary circuit may be produced by some mechanical device separate from the coil, or by the peculiar electrolytic arrangement known as the Wehnelt interruptor. The ordinary hammer answers very well for coils up to six inches; even with ten and twelve inch coils a large amount of the work done with X rays is carried on with the vibrating hammer interruptor. To improve its action it is fitted with a "tension screw," by turning which the hammer can be made to resist the pull of the magnetism of the core to a greater or less extent. The adjustment of the tension screw enables changes to be made in the working of the coil for purposes of regulation. If a few experiments are made with a long spark induction coil, it will soon be found that small adjustments of the tension screw of the contact breaker produce very great effects in the length of spark which the apparatus can be made to give out. Thus, with the contact breaker spring quite loose, a six inch coil will only give sparks of one or two inches, and the sparks can be made longer and longer by increasing the tension of the screw of the contact breaker. When working with the coil the tension screw must always be adjusted to suit the work which is required. Thus, at times it may be advantageous to screw up the tension spring of the contact breaker so tightly that the full strength of the battery is necessary to make it work. Under these conditions the primary current is only broken when the full current is flowing in the primary, and the full magnetising effect upon the iron core is developed. A sudden break of current at this moment gives the maximum effect of which the coil is capable. When working with a tightened tension spring it is necessary to stand by the apparatus while it is at work, lest

the platinum points of the vibrator may stick, and the rush of current which follows may damage either the accumulators or the coil. It is also necessary to take care of the platinum contacts of the contact breaker. They burn away gradually, and their surfaces become uneven and need to be filed from time to time, to give them flat, smooth, clean surfaces, if the coil is to work satisfactorily. New platinum points must be fitted when the old ones are worn away.

The Vril contact breaker is a modified form of hammer break which is made by W. Watson and Sons. It will be seen from

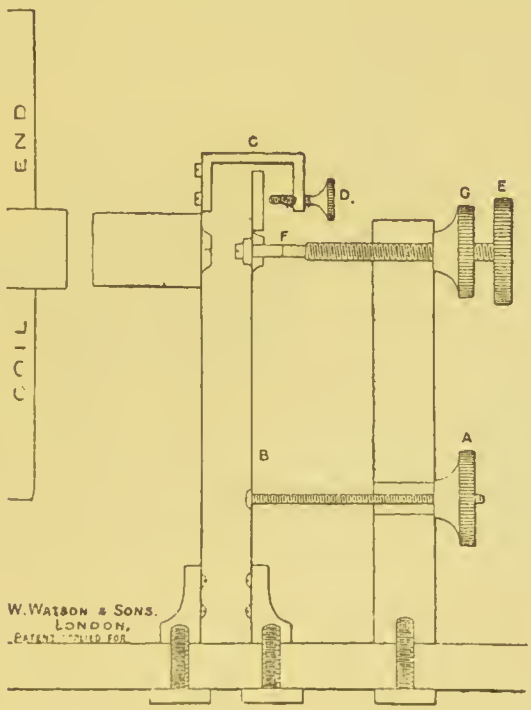


FIG. 31.—Vril contact breaker. A. Head of tension screw.

fig. 31 that the iron hammer is mounted as usual, but the platinum contact F is carried by an intermediate spring, B.

When in action, the attraction of the hammer by the core causes the point of screw D to impinge on the top of spring B, so causing a separation of the platinum points, F. The advantages claimed for this break are that a more prolonged contact is afforded, giving time for the thorough magnetic saturation of the core; that in consequence there is an economy in the expenditure of battery power, as compared with ordinary patterns, and that the break is more sudden and the wear and tear of the

platinum contacts is diminished, while "sticking" is almost impossible. It is a good form of break. The idea is an old one, and similar forms of breaks are fitted to coils by other makers, and in some of these an independent electromagnet is used to operate the movement.

Many workers with Röntgen rays still use the ordinary vibrating spring contact breaker described above, and for photographic work this contrivance gives very good results even with coils giving sparks up to twelve inches. Where steadiness and rapidity of action is desired, as for instance, in Röntgen ray examinations with the fluorescent screen, the hammer interruptor must be replaced by some form of mechanically driven motor break, or by the contrivances of Wehnelt or Caldwell, the so-called electrolytic breaks.

All high speed breaks require high electromotive forces to give good results. Consequently there is not much advantage in using a rapid break unless a good number of accumulator cells can be used. If an experiment be tried, it will be found that the sparks given out by a coil fed from a small number of cells will become feebler as the speed of the mechanically driven break is increased, while if the number of accumulator cells in circuit be increased the sparks will become longer for the same speed of breaking circuit.

On the other hand, with a vibrating spring contact breaker the electromotive forces applied to the coil cannot safely be increased beyond a certain point, whereas with a sufficiently rapid break, electromotive forces up to 100 volts, or higher, may be used with advantage, provided the speed of the break be increased in due proportion, and in this way we arrive at the direct employment of the electric lighting mains (continuous) for working large coils, a method which is only possible with rapid contact breakers.

70. **Mechanical interruptors.**—Many forms have been devised, and for purposes of description they may be arranged in groups. The oldest form is one in which the contacts are made and broken by a rod which is made to dip into and out of mercury (see fig. 32). The movement of the mechanism is usually effected by a small electromotor driven by an independent battery, and the speed can be varied by the regulation of the current supplied to the motor. The range of movement of the rod or plunger, which dips into the mercury, can be

adjusted, and the best conditions are obtained when the moving plunger is in contact with the mercury for a relatively long part of the period, and leaves the mercury when moving with its greatest velocity, which is when the crank is nearly at right angles to the axis of the moving plunger. These "dipper" mercury breaks are useful for medium speeds, but at high speeds the surface of the mercury is displaced, and the interruptions become irregular.

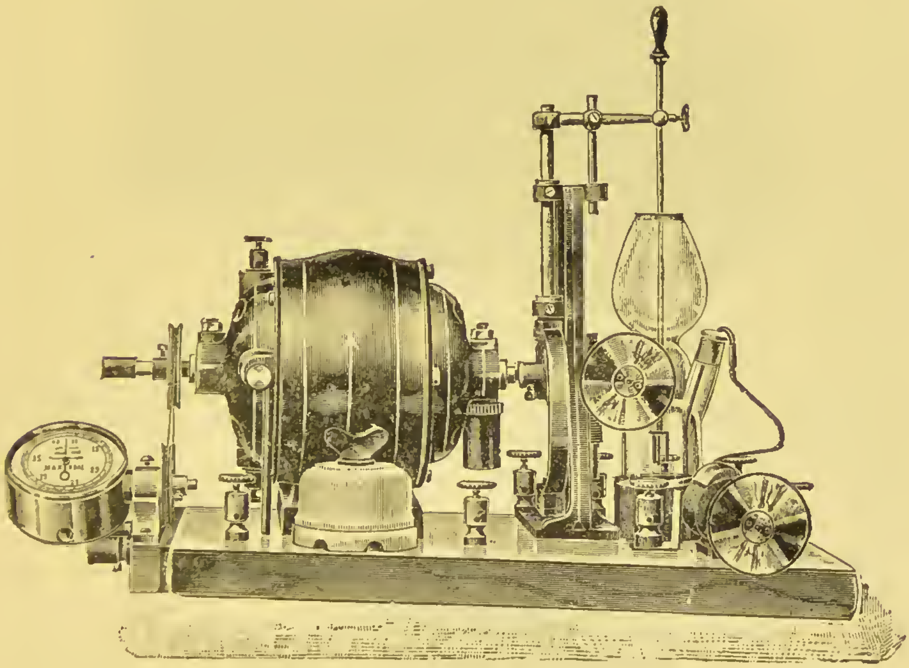


FIG. 32.—Dipper break fitted with speed counter.

For the high speeds which are necessary with high voltages of supply, a rotary interruptor is a more satisfactory instrument than a "dipper" break. Mercury is employed in most of them, but not in all.

Whenever mercury is used in these interruptors it is kept covered by a layer of alcohol or of paraffin oil, to quench the sparks. After a time these liquids become dirty, owing to the emulsifying effect produced by the churning movements of the apparatus.

Among the rotary breaks using mercury, two of the simplest and best are the following:—

The Mackenzie Davidson break. Fig. 33 shows this interruptor. It consists of an inclined metallic axle with projecting

blades, which come into contact with the surface of a bath of mercury when the axle is revolved. It can be driven at a high speed, which is regulated by a variable resistance in the motor circuit. It acts very efficiently.

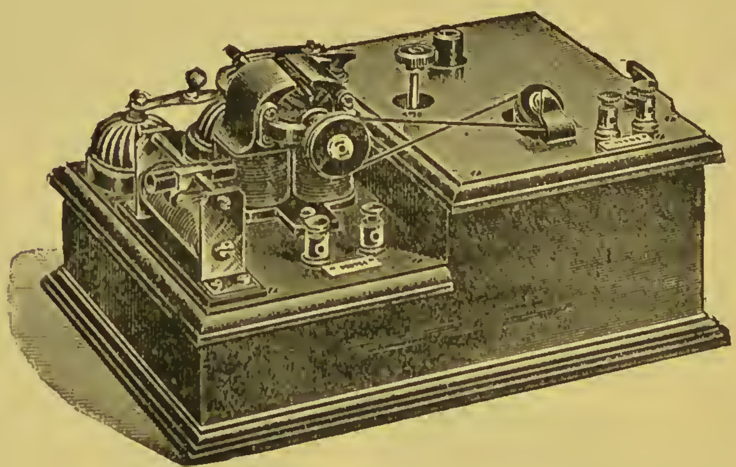


FIG. 33.—Mackenzie Davidson's interruptor.

The turbine mercury break (fig. 34), invented by Max Levy, is a cleverly designed interruptor in which a jet of mercury, which is continually pumped up by centrifugal power from the

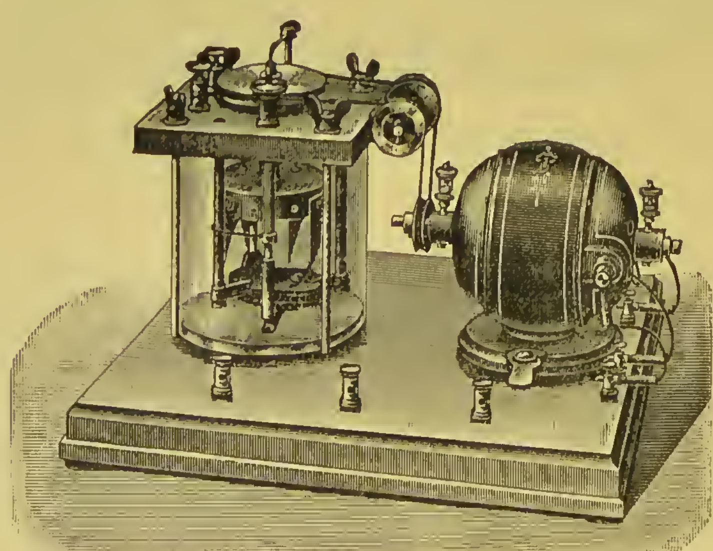


FIG. 34.—Turbine break.

bottom of a jar, strikes on a series of teeth cut in a cylindrical piece of metal which forms the other contact. This interruptor gives the best results and has come into general use. In

addition to its other good qualities this interruptor has the advantage that current cannot flow through it except when it is in motion, and this safeguards the coil. The rapidity of the interruptions is perfectly under control, and can be varied to any extent, and an absolutely steady stream of sparks is obtained. The duration of the contacts can also be varied by raising or lowering the cylinder as its segments are tapered off below and are wider above. It is nearly silent in action.

The three types of interruptors just described are to be found, with various modifications, in the catalogues of different instrument makers. The turbine break has been improved by an alteration in the position of the motor which enables it to drive the break with a straight belt. In the "Wodal" form of the instrument the same result is attained. Another interruptor which may be mentioned resembles the turbine break in appearance, but the contacts are made between copper brushes and revolving copper plates. A little mercury is used in this form of interruptor to amalgamate the moving surfaces and so to improve the contacts. Under the name of the Contremoulins-Gaiffe interruptor it is extensively made use of in France, and it is also well known in this country.

71. **Electrolytic breaks.**—The most rapid break of all is the liquid or electrolytic break of Dr. Wehnelt. This depends for its effect upon the formation of bubbles of gas at the poles of an electrolytic cell. When one pole is of small surface, the bubbles of gas formed there render the current intermittent, the interruptions following each other with extreme rapidity.

It is interesting to note that Spottiswoode employed a contrivance of this kind for use with coils, and spoke of interruptions with a frequency of 1,000 a second obtained in that way.

Wehnelt's break, as usually constructed, consists of a glass jar or vessel filled with dilute sulphuric acid; the kathode is a sheet of lead, while the anode is a platinum wire insulated except at its extremity, which is deeply submerged in the electrolyte. Means are provided for increasing or decreasing the exposed area of the platinum. When a steady electromotive force, which must be of at least 24 volts, and may be as high as 150, is applied to the apparatus, arranged in series with the primary circuit of a coil, the discharge through the circuit thus formed becomes intermittent, a peculiar shrill note is given out by the electrolytic cell, and streams of sparks are given off by

the secondary coil. The liquid in the cell heats rapidly and the platinum point must be readjusted if it is to work at a higher temperature. The contact breaker proper of the coil must be screwed down, and this throws the condenser out of gear, but as the coil works equally well without it at these high speeds of interruption this is of no importance. Care must be taken to ascertain the direction of the current before connecting up the Wehnelt interruptor. If connected wrongly the platinum point will probably

FIG. 35.—Wehnelt interruptor.

fuse and be destroyed. In any case it wears away rapidly, and this is a source of expense.

A solution of sodium or potassium hydrate may be used instead of sulphuric acid for the electrolyte, and in this case iron can be used for the anode and kathode and this saves the cost of the platinum, but increases the resistance of the cell somewhat. This modification has not yet come into practical use. A saturated solution of alum may also be used instead of sulphuric acid for the electrolyte.

In Wehnelt's apparatus the intermittent character of the discharge is due to the formation and dissipation of gas bubbles at the anode. There is a modification of the apparatus of a fundamental kind due to Caldwell and also independently to Simon.

These observers bring about the formation of bubbles of gas at a point in the cell remote from the poles, and thereby secure several advantages. There are several forms of the Caldwell interruptor. In the usual type the electrolytic cell contains the usual acid—dilute sulphuric acid, and there are two plates of lead for the anode and kathode. The use of platinum is ren-

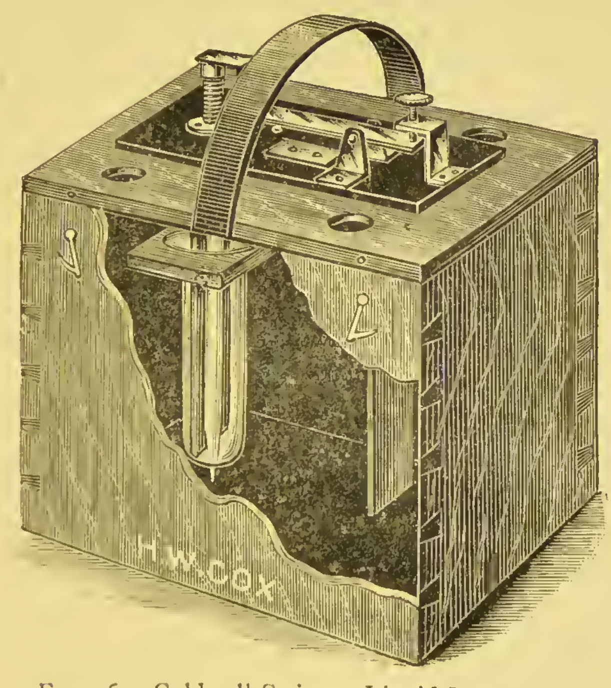


FIG. 36.—Caldwell-Swinton Liquid Interruptor.

dered unnecessary. A partition of glass or porcelain separates the cell into two parts, each containing one pole. The partition has a small hole through which the liquid in the two portions of the cell communicate. Owing to the high density of the current at this narrow opening, that portion of the circuit becomes heated, and bubbles of gas (steam) are generated there and break the circuit. The bubbles are almost instantaneously dissipated and as quickly renewed, the rate being in part determined by the magnitude of the current and by the size of the hole.

In one of its forms (fig. 36) the apparatus consists of a wooden box containing a glass receiver with an inner cylindrical vessel of glass, suspended so that it does not rest upon the bottom. This inner cylinder has a small hole at the lower end about three or four millimetres in diameter. Into this hole projects the conical end of a glass rod fixed in a vertical position and attached to an adjustable screw so that it can be raised or lowered as required. In this way the aperture can be opened or closed wholly or in part by altering the position of the rod. The frequency of the interruptions also varies as the size of the aperture is altered. Connections are made by means of terminals attached to two lead electrodes dipping into the inner and outer vessels respectively. When operating, the liquid is found to rise in the inner cylinder, which is accordingly provided with an overflow channel through which the liquid returns into the outer vessel. As both poles are of lead and of large area, there is no special need to make the connections in one particular way as required for Wehnelt's form.

With either of these liquid interruptors the appearance of the discharge of a coil is considerably altered. The sparks from the secondary terminals give the appearance of torrents of sparks passing simultaneousiy, although in reality they are successive, but follow each other at very short intervals of time.

The account just given of Rhumkorff coils and interruptors may leave the reader in some doubt as to the choice of an outfit best suited to his requirements. With regard to interruptors the platinum break or hammer interruptor has the advantage of simplicity, especially when the induction coil may be wanted at a patient's bedside. The hammer interruptor is therefore useful, and serves well as a reserve in case the other interruptors should fail. Much good work is done with coils fitted only with this form of interruptor, and some workers believe that sharper X ray photographs can be obtained with it than with other forms of break. In other respects it is inferior to the mercury interruptors, and works much less regularly. The electrolytic breaks of Wehnelt and of Caldwell are cheap, but they are rather noisy, and are unnecessarily rapid for most medical applications.

In X ray work they are likely to damage the tubes by over heating, and there is a certain danger of the spilling of corrosive acids in case of accident to the containing vessels of these

interruptors. Of the mercury breaks the best are the rotary break of Mr. Mackenzie Davidson for use at medium pressures, and the turbine break in one or other of its forms for direct use from the street mains.

With regard to the windings of the primary coil it may be said that for most work the simple series winding is the best. Its higher self-induction acts as an useful choke when the coil is driven with high pressures, and keeps down the expenditure of current. At the same time it keeps down the electromotive force of the inverse discharges at "make," and so protects the X ray tube. A rearrangement of the primary layers in parallel is sometimes useful for electrolytic breaks, if it is desired to produce sparks of the full length of which the coil is capable.

CHAPTER IV.

Medical batteries. Accumulators. Accessory apparatus. Electrodes. Resistances. Galvanometers.

72. **The portable medical battery.**—In choosing a battery for medical purposes the essentials are to have one which is efficient and does not require frequent attention. In many cases it is necessary to carry a battery to the houses of patients, therefore, portability must not be lost sight of. Medical batteries are sold by electrical instrument makers consisting of from 25 to 40 cells arranged in a case, and fitted with commutator, current collector, galvanometer, and with an induction coil. This arrangement is commonly called a "combined battery." These are quite suitable for testing the reactions of nerve and muscle, for general medical treatment, and for electrolysis. The cells used are either small Leclanché cells or "dry" cells. Owing to their small size their capacity is not large, and they cannot long give out large currents without becoming exhausted, but with proper care they may be counted upon for twelve months of steady work for all ordinary purposes of testing and treatment, including occasional use for the electrolysis of nævi, an operation which demands fairly large currents. After that time they will require recharging or renewal. The best plan perhaps is to use small dry cells, and to discard them altogether when exhausted. The medical Leclanché cell costs more on account of its ebonite case, and these, if returned to the makers, can be allowed for, but it is better not to be troubled with them. If used, they last longer when charged with zinc chloride solution, one part to six of water, but as the cells are generally sent out from the makers with the charge of sal ammoniac inside them, they must be washed free of this before putting in the zinc chloride. The dry cells cost only about eighteenpence each. For working the induction coil in portable medical batteries two separate cells of larger size are fitted; as these run down more rapidly than the others they require renewal more frequently, and should be so placed in the battery as to be easily reached for this purpose.

Catalogues may be consulted by those wishing to purchase a medical battery. The details of the fittings of portable batteries vary with the different makers, but instructions for use are usually supplied with the instruments.

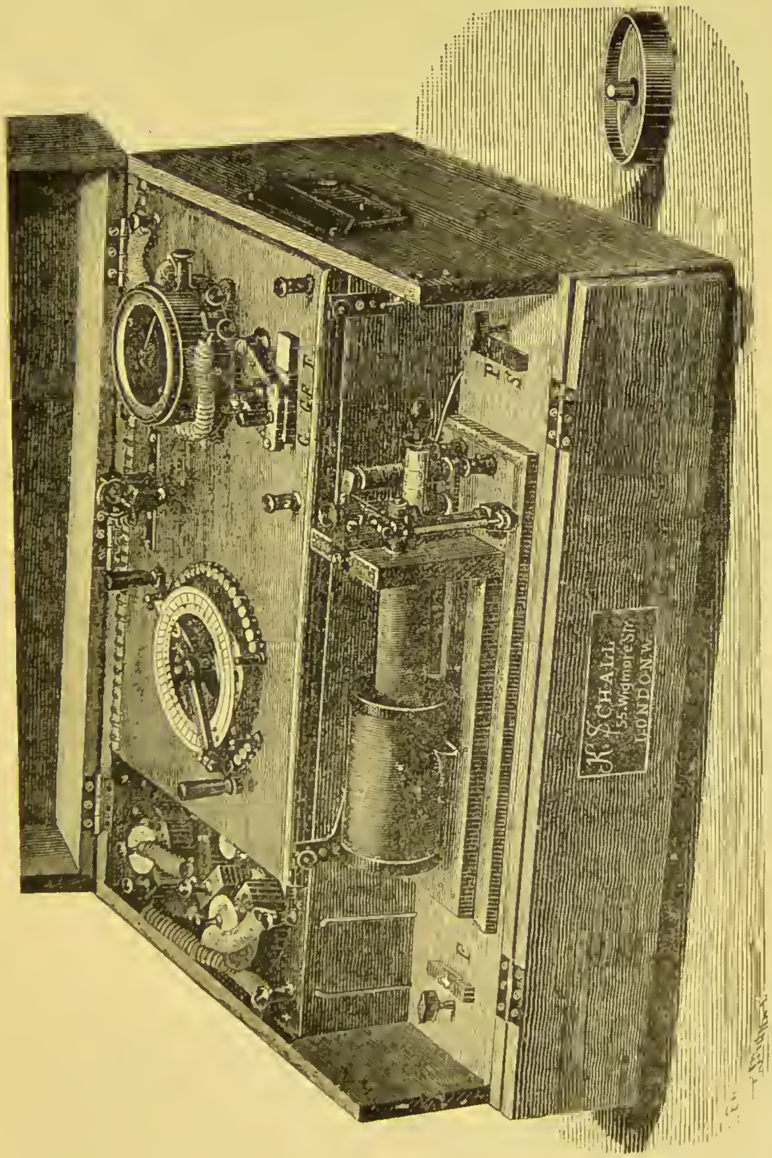


Fig. 37.—Schall's combined battery.

There is no need to have a fixed installation in the consulting room as well as a portable combined battery, for the latter will serve at home as well as in the houses of patients, and as all battery cells tend to deteriorate in time whether they are used or not, there is twice the cost of maintenance with two batteries

that there is with one. Naturally it is convenient sometimes to have a fixed installation of large cells at home, as well as a portable set; but it is more economical and less troublesome to have few batteries.

Although it is in many ways a convenience to have the coil and the battery of cells combined in one instrument, the medical man is likely to find it convenient to have a separate portable induction coil, as the possession of such an instrument may sometimes obviate the need for carrying about a heavy com-

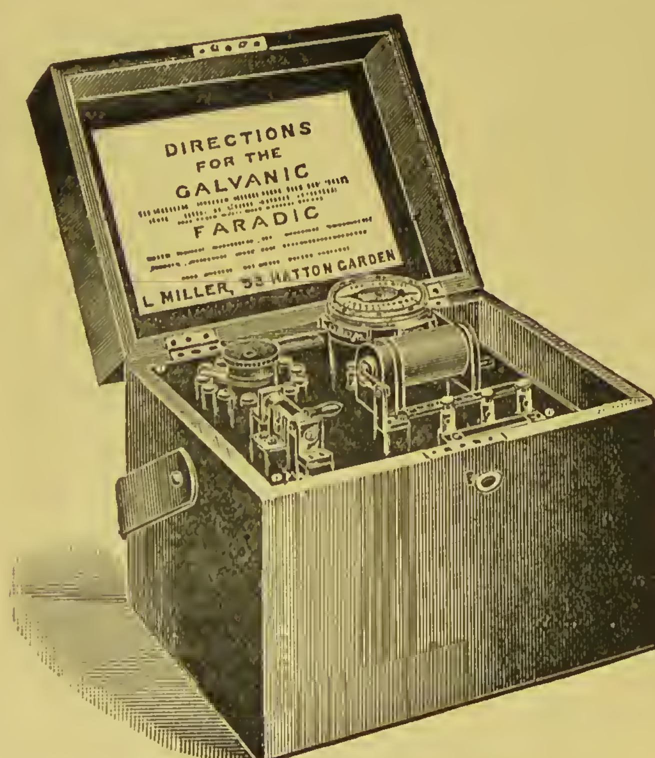


FIG. 38.— Combined medical battery.

bined battery. So, too, one may obtain simple batteries of cells arranged in boxes at low prices, which are often useful when it may be desired to lend a battery to a patient. For details of these batteries the instrument makers' catalogues should be consulted.

73. **Stöhrer's battery.**—This battery, once largely used in medical work, and still met with occasionally in remote places, is a modified form of bichromate battery. The elements, zinc and carbon, are arranged in a double row, on a wooden bar,

so that a double row of glass or earthenware cells containing the exciting fluid can be raised up to them in such a manner that the correct pairs of plates dip into each cell (see fig. 39).

The battery is made up to contain 20, 30, or 40 cells, arranged in a double row in a strong oak box, and a beam of wood with a deep channel cut in it extends from end to end of the box in the middle line; the pairs of plates are all suspended from this beam by brass rods, which convey the current from the cells to a travelling collector running in the channel.

The collector which slides in the groove of the beam carries two flat brass springs which make connection with the brass

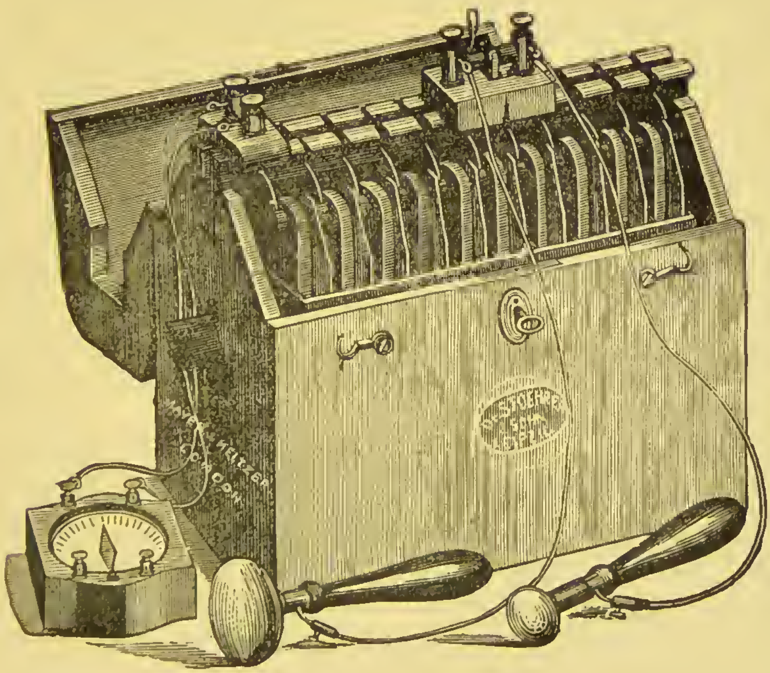


FIG. 39.—Stöhrer's battery.

rods from which the pairs of plates hang. From the springs the current goes through a commutator to a pair of binding screws, for the attachment of the wires and electrodes. It may be noticed that Stöhrer's battery was originally designed for use with dilute acid only, as in Walker's modification of Smee's cell, but the addition of the chromic acid depolarizer obviously improves its action.

The battery is not portable owing to the quantity of corrosive liquid in the cells, and it is troublesome to keep it clean, and its zinc plates amalgamated. It is therefore becoming obsolete.

The plan of its construction is very simple and might be revived with advantage for use with dry cells.

For heating cauteries and for electric light instruments, a four cell accumulator provided with proper regulating resistances is the best apparatus, unless the recharging is an obstacle. In that case a four-cell bichromate battery of large size, with proper connections, will serve the same purpose.

Details of lamp and cautery batteries and instruments and their management will be considered in Chapter XVI.

74. **Care of batteries.**—The trouble of keeping batteries in order is commonly put forward as an excuse for neglecting electricity in medical practice. As a matter of fact, with a proper modern battery there is no trouble worthy of mention. It is important in buying a battery to choose one which will remain in good order without much attention. On this account acid cells are to be avoided.

Care must always be taken to guard against accidental or intentional short circuiting of any battery. Few batteries will stand short circuiting for many minutes; the dry batteries most used in medical practice are particularly sensitive to it. Short circuiting may easily occur if the electrodes are carelessly thrown down after use, and should happen to lie in metallic contact with each other.

It is bad practice to try to test a battery by connecting the terminals by a direct metallic contact except through a coil of high resistance, for the strength of current may be so great as to damage the galvanometer, and it will probably be too large even with one cell for a galvanometer graduated in milliampères to give readings of it. If no resistance coil be at hand the plan of putting the electrodes into a little water in a saucer will usually suffice to reduce the current in the circuit to a quantity which can be measured in milliampères. If the battery be not fitted with a galvanometer, one must be attached for this mode of testing. It may be connected to the terminals of the battery, in series with the resistance employed. If this has a value of about 1,000 ohms the current is reduced to a magnitude suitable for measurement with the milliampère meter; the pointer must then be gradually moved round the studs, the galvanometer being watched carefully. If the battery is in proper order it will indicate a regular rise in current step by step, for every cell added to the circuit. If the galvanometer needle falls to

zero as the pointer is passing from one stud to the next, it indicates that the current is broken at that moment, and if a patient was in circuit he would receive an objectionable shock. If the needle falls to zero when the pointer is on a stud, it shows that the connection between that stud and the battery is faulty.

When a battery has been dismounted and put together again, especially if it has many complex connections, there is a danger that the positive pole may have been accidentally connected to the binding screw marked negative and *vice versâ*. This is sometimes the case even when the repairs have been done by an instrument maker. This is an important point because confusion of the poles may lead to serious mistakes and even to injury to the patient. All risk can be done away with by the use of some method of testing the polarity of the electrodes. It is easy to improvise one. A piece of wet litmus paper on a sheet of glass, will show by changes in colour at the electrodes which is the positive and which the negative pole. The ends of the wires from the battery must be rested on the paper for a few moments, electrolysis will take place and the litmus will be reddened by the acid liberated at the anode or positive pole, and will turn blue at the kathode or negative pole. Other reagents have been proposed, for example, a solution of phenolphthalein in dilute alcohol answers very well, giving a purple red colour at the kathode or negative pole.

To keep a bichromate cell in good order it must be attended to. If its action fails and the liquid is found to be dark green in colour it must be renewed, if it is still orange a dose of strong sulphuric acid will restore it for a time. The materials for making fresh solution can be bought in a dry form in bottles, ready mixed. The battery requires to be taken down occasionally, the carbon plates to be soaked in water and brushed with an old tooth brush, and the zincs to be washed clean and amalgamated: for this they should be scraped smooth and wetted with dilute acid and then some mercury should be well rubbed into them with a stick of wood wound round at the end with worsted. The surface when properly amalgamated looks as bright as silver and should appear to be wetted by the mercury at every point.

The zincs must never be left in the chromic solution when not in use, as it attacks zinc readily.

To charge an accumulator from a primary battery, the latter

must have an electromotive force greater than that of the cells to be charged. For a two-celled accumulator, five Daniell cells, three bichromate, or Bunsen cells, or seven Edison-Lalande cells are required. The charging cells should be large, the process is as follows:—The primary battery having been freshly charged, coupled in series, § 34, and tested to see that it is in good order, it must be attached to the accumulator, positive pole to positive pole, and negative to negative. Current will then pass to the accumulator from the battery so long as its electromotive force keeps up above that of the secondary cells. The current will slowly diminish as the primary cells run down; when the electromotive forces of the primary and secondary cells are in equilibrium, no current passes in either direction; if the primary cells run down more, the current may set in the other direction and the accumulator may discharge itself through them, and thus defeat the object of the charging operation.

The operation must accordingly be watched and stopped before the charging current has fallen to zero. A suitable ammeter, see § 84, will show the magnitude and direction of the current which is passing. By noting the magnitude of current at intervals during the charging process, an idea is obtained of the amount of the charge. For example, suppose the duration of the charge be six hours, and the current during the first hour be three ampères, during the second and third hours two ampères, during the fourth one ampère, and during the fifth and sixth half an ampère, then the charge will be in ampères for each hour, 3, 2, 2, 1, $\frac{1}{2}$, $\frac{1}{2}$, or 9-ampère hours.

75. **Accessory apparatus. Conducting wires.**—The conductors or leads by which the current is conveyed from the battery or other generator to the place where it is to be used, should be of insulated flexible copper wire. Copper is used because it is the best conductor among metals with the exception of silver, which indeed is not very much better, and is out of the question on account of its cost. It is best to use insulated wire to avoid any risk of shocks or short circuiting from the wires coming into accidental contact with one another. Suitable wires may be bought insulated either with cotton or silk or india-rubber, and for cases where the current has to be conveyed some little distance it may be convenient to use double conductors made of two insulated wires twisted together. In this case it is well to mark the ends, so that there may be no difficulty in

recognizing the positive and negative wires. A pole tester, § 74, will prove useful for this purpose. It is useful to have the two conductors covered in two different colours, say red and green, as it makes it more easy to distinguish between them, in tracing their attachments to the battery or to the electrodes. A convenient length is four feet and a half or five feet. Suitable cords with ends to fit the battery terminals are sold by the instrument makers. To find really good ends for the conducting cords has hitherto been a matter of difficulty. Dr. George Herschell* has lately drawn attention to the merits of the "adjustable cord tip" of the McIntosh Company of Chicago, which appears to solve the difficulty very satisfactorily (fig. 40). He recommends for use with these tips a rather thick kind of conductor, known in electric lighting circles as "arc-lamp flexible."

FIG. 40.

Mr. Dean† can supply this cord with tips which are almost identical with those figured. To attach the tips the wires in the cord are denuded at the extremity, passed through the hollow screw and knotted, and the point piece is then screwed on over the knot, and holds it tightly.

It is important to know that the wire core of these covered cords may become broken inside the covering, and give trouble if not discovered, the commonest breaking point being near the ends. Faulty connections are among the regular accidents tending to throw electrical apparatus apparently out of gear, and although it is not hard to detect the fault by careful examination, yet only too often much difficulty is found, and in consequence the battery is condemned, or the services of the instrument maker are called in. It need not be said that this is the wrong way of doing things, for everyone using a battery should make himself familiar with the proper management of it, in order to avoid the expense and annoyance of perpetually putting it into the hands of an instrument maker.

* "Manual of Intragastric Technique," London, 1903.

† 73 Hatton Garden, E.C.

As a matter of fact with moderate care no difficulty need occur from faulty contacts. It is advisable for the sake of neatness to use but one form of binding screw, as far as possible. There are of course many forms in constant use, and a few minutes may be well spent in inspecting an electrical instrument maker's stock.

76. **Electrodes.**—The conductors through which the current is applied to the body are called electrodes. The word electrode has also been used to describe the connections by which the current leaves the battery or enters any instrument, and also the wire conductors of a circuit, but in medical usage the word electrode is employed to signify the special terminals which are applied to the patient. The special terminals used in medical treatment were formerly called rheophores. The variety in nature and shape of the electrodes used in medical practice is naturally great, and it will be useful to describe some of them at this point.

The old-fashioned brass handles and wet sponges should be wholly abandoned, and the proper form of electrode to use is a disc or plate of metal covered over with chamois leather, or some such absorbent material.

Care must be exercised to keep the electrodes clean, and on this account metal is a better material for electrodes than carbon. Uncovered metal must not be applied directly to the skin, as it may produce painful effects, or may even cause sores, by electrolytic action upon the surface of the skin. On this account sheaths and covers must be fitted of one or more layers of amadou, or flannel, or chamois leather. These should be often renewed, and as far as possible a separate set should be kept for each patient. Absorbent cotton-wool, asbestos cloth, and blotting paper have also been used with advantage for sheaths to electrodes.

In some medical applications both the poles of the battery are used equally, and in that case the electrodes at the two poles may be similar, but more often the current is applied to the affected part with one pole, which is then known as the "active electrode," the circuit being completed by the application of the other electrode, the "indifferent electrode," to any convenient part of the body; under these circumstances the active electrode may require a handle for its proper manipulation, while the indifferent electrode is most conveniently arranged as a simple

metal plate, which can be applied to the surface of the body and left there during the treatment. It is generally an oval plate of pure tin or pewter four or five inches long. Zinc plates may also be used, and perhaps the best metal of all is silver. Thin sheet silver is not very costly. It looks clean and has the advantage that its chloride is insoluble and remains on the surface of the plate, where it is harmless. On one side of the plate a binding screw is affixed for the attachment of the battery wire, and the other side is covered with a smooth piece of amadou or chamois leather, which must be moistened with warm water before use. In addition there should be a sheath or pocket with

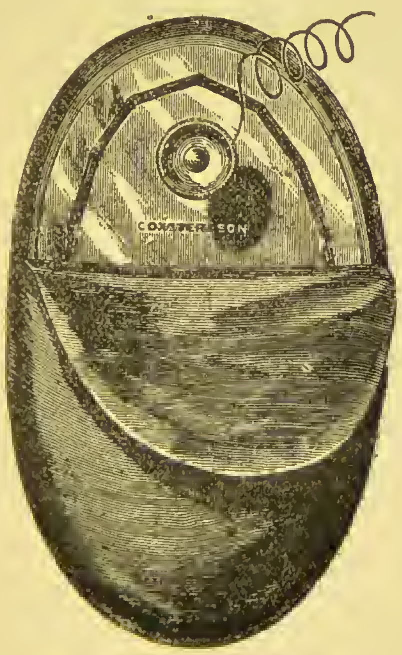


FIG. 41.—Indifferent electrode and sheath.

a mackintosh back to contain the electrode (fig. 41), this will serve to protect the patient's clothes from being wetted without interfering with the passage of the current. Red Turkey twill makes a nice material for the front side of the sheath.

The indifferent electrode may be slipped between the clothing and the skin, the pressure of the clothes will then suffice to keep it in place, or if the patient is lying down, the electrode may be put underneath the shoulders or the hips, or it may be held against the body by the patient himself, or by an attendant. In either case the operator is able to give his whole attention to the

other or active electrode. Care must be taken to see that the contact of the indifferent electrode with the skin is well maintained, and that no dry clothing lies between. Sometimes, especially with children, it may be fastened on by a few turns of a bandage, or by a soft garter or belt of some kind. Electrodes to buckle or clasp upon a limb are figured in the catalogues, and are useful. The precaution should be taken of seeing that the proper side of the sheath and the proper face of the electrode are together, for the waterproof side will not conduct.

Several sizes are required. Professor Erb has suggested the adoption of electrodes of standard sizes, because the density of the current and the effective resistance of the surface at the point of entry depends upon the size of the electrode, that is to say, the area from which the current passes to the patient. For different effects one may desire at one time a current diffused over a large surface of entry, and at another a current concentrated at a small surface. In the operation for the removal of

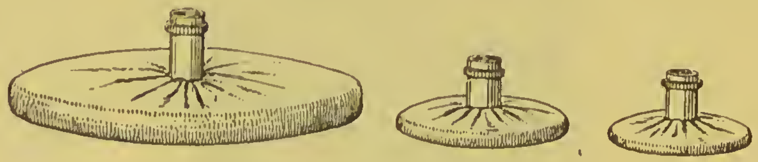


FIG. 42.—Electrodes.

superfluous hairs by electrolysis, the indifferent electrode is large and the local effects on that part of the skin which it touches are imperceptible, but the active electrode is a fine needle, and the density of the current at its point is such that strong local effects are produced where it pierces the skin, even when the current is only two or three milliampères. By using standard sizes one can more readily convey to others a correct idea of the current density used in any particular case.

For practical purposes of diagnosis and treatment it will generally suffice to have three or four sizes of disc electrode, the smallest of half an inch or one centimetre in diameter, the largest of three or four inches. A roller electrode and a fine wire brush are also necessary at times.

A very good form of disc electrode is made, in which the operation of renewing the wash leather covering can be quickly carried out without needle and thread. The electrode is made of two cupped discs of metal, which screw together, and so hold

the edges of the wash leather firmly fixed between them (see fig. 43).

The more special forms of electrode will be described and figured in the chapters which deal with the particular operations in which they are used.

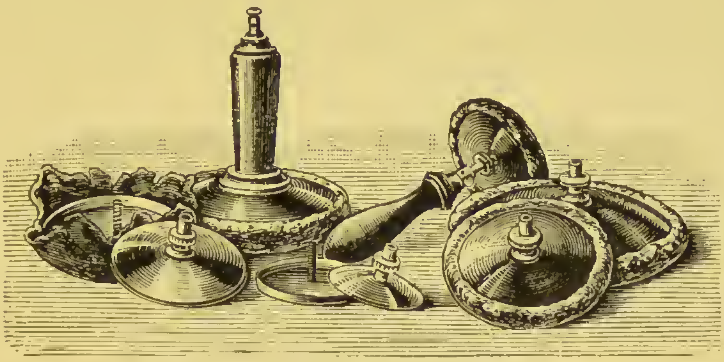


Fig. 43.—Electrodes.

For testing purposes an electrode with a key for closing the circuit is necessary. Electrodes with opening keys are much less useful.

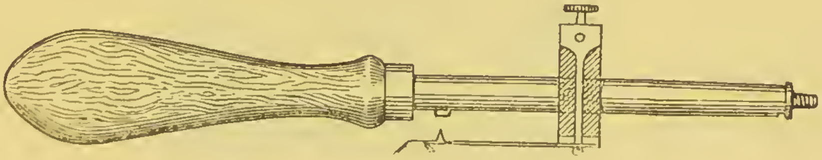


Fig. 44.—Testing electrode with "closing key."

77. **Current collectors.**—Medical batteries for galvanic treatment are made up of a large number of cells (20, 30 or 40 arranged in series), but the number of cells to be used in different cases varies very much. On this account a quick and simple plan of altering the number of the cells included in the circuit is required so that the current may be readily increased or diminished to suit the needs of each case by switching cells in or out of circuit. The plan is as follows:—

In the diagram, fig. 45, six cells are shown numbered I. to VI., they are joined in series, and from the terminals wires are led off to seven corresponding studs numbered 0 to 6. It may be seen that a movable metallic arm springing on to stud No. 1 will throw one cell into circuit between the binding screws

marked + and −, and similarly when the arm is placed on any other stud it brings into the circuit the number of cells shown by the figure marked against the stud.

This is in brief the principle of the current collector, as applied to medical batteries, the stud marked o being connected with one pole, say the positive pole of cell No. 1, and leading to a binding screw marked +, stud No. 1 being attached to the negative pole of the same cell and when the movable arm touches stud No. 1, the current passes along it and from there goes to the other binding screw of the battery marked as shown in the figure. Cell No. I. only is then included in the circuit; if the pointer be transferred to another stud, numbered let us say 6, then six cells are in circuit and are being used.

A more complicated current collector has been devised, by means of which the current may be taken from any cell or any

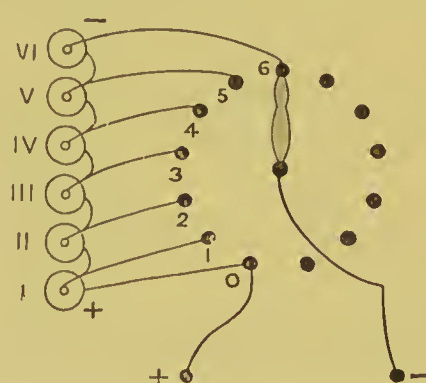


Fig. 45.—Plan of a single current collector.

group of cells commencing at any point, the advantage being that the cells can be used equally. In the single collector the first cells are always drawn upon, and are likely to run down before the last cells, which are only needed occasionally. With the double collector if six cells are required not only could cells 1 to 6 be chosen, but cells 4 to 9, or 7 to 12, or 13 to 18, or any other set of six. With the single collector the first cells must always provide current and cell No. 12 can only be used when eleven cells are insufficient. Accordingly, with a single collector, the last cells of the series are very seldom called on at all, while the first cells have to do duty every time the battery is used. Another advantage of the double collector is that with its aid the working of every cell of the battery can be separately tested; the double collector, however, is rather more expensive.

If in the figure of the single collector (fig. 45) the wire leading from cell No. 1 to the stud numbered 0 were not continued to the positive terminal of the battery, and if this latter were connected instead to a second arm, pivoted on the same axle, but electrically insulated from the first one and capable of independent movement (fig. 46), it can be seen that with the two arms on the studs 3 and 6 the current would be taken from cells 4, 5, and 6 only, that is to say the group of cells 4 to 6 would supply the current to the circuit. In like manner any number of consecutive cells from one upwards could be picked out from any part of the whole series. It is usual for one of the arms to carry a circle so divided and numbered as to read off directly the number of cells in use.

Fig. 46.—Double collector.

The studs of current collectors must be of good size, and the pointer just broad enough to touch two at once, that the number of cells in the circuit may be increased or diminished without breaks of current and unpleasant shocks at the moment when the pointer moves from one stud to the next. At the same time care must be taken that the movable pointer of any collector is not left for any length of time in contact with two studs at once, for when it is in that position one cell is short-circuited and its energy is being wasted. This waste can be reduced by the use of a collector having a longitudinal divided arm, with its two portions joined through a resistance of fifty ohms.*

78. **Commutator or current reverser.**—An apparatus for

* This is provided in Mr. Miller's batteries.

reversing the direction of the current in the external portion of the circuit is indispensable for some medical purposes. It is difficult to make a satisfactory examination of the reactions of nerve and muscle without one.

Rhumkorff's commutator (fig. 47) consists of a cylinder of

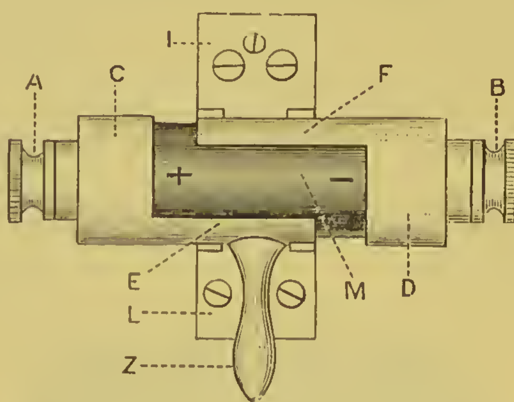


FIG. 47.—Commutator of Rhumkorff.

vulcanite M, having at each end a metal cap or ferrule C, D, and supported between two uprights in such a way as to revolve easily about an horizontal line, each end is connected to a binding screw A, B, and each metal cap is prolonged in the form of a check E, F, along one side of the vulcanite cylinder for two-thirds of its length. On either side of the cylinder, springing

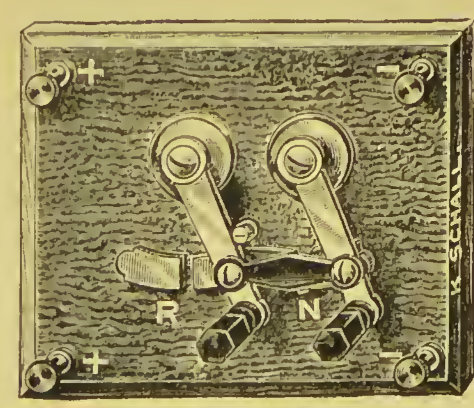


FIG. 48.—De Watteville's commutator.

against it, are two pieces of metal I and L, connected with the terminals of the battery. When the cylinder is turned by means of the handle Z, either of the metal checks can be brought into contact with each of the springs I, L. The positive pole of the

battery connected say with L, can thus be brought into connection with either the binding screw at A, or at B, so that the current can be made to pass in either direction at will round the external portion of the circuit between A and B. The + and − signs on the vulcanite cylinder indicate the polarity of the binding screws; in the position shown A is positive, a half revolution of the cylinder alters A to negative, and therefore the reverse side of the cylinder, which then comes into view, will have the + and − signs transposed also.

Another form of commutator is shown in fig. 48. In this the two crank arms move together. In the figure N stands for normal, R for reversed.

79. **Regulation of current. Resistances.**—When the current is regulated as described in § 77, it will be seen that, neglecting the resistance of the battery, the electromotive force is the only thing altered in the circuit. But by Ohm's law we know that the current is numerically equal to the electromotive force divided by the resistance of the circuit, so that it might be regulated by introducing or removing resistances, the electromotive force being kept constant. In some cases it is more convenient to regulate by this method, as for example, in regulating the current from the electric light mains, where the electromotive force is maintained at a constant figure. An adjustable resistance for varying the current in a circuit is sometimes called a "rheostat." In general, with batteries, when the total resistance of a circuit is large, it is more convenient to alter the electromotive force than the resistance in the circuit. Thus, suppose a circuit has a total resistance of 3,000 ohms, and is acted on by twelve cells of 1·5 volts each, there will be a current of six milliampères; if now it is required to double the current, it is easily done by adding twelve more cells, taking for granted that their internal resistance may be neglected, but if it were desired to make the alteration by reducing the resistance of the circuit, it would be necessary, in order to double the current, to take out a resistance of 1,500 ohms, which might be impracticable. When it is desired to increase current by taking out resistances, it is of course requisite that the resistances to be removed must first be connected up in the circuit before the commencement of the operation. If the total resistance is small this can be done, and in such cases the current is most easily governed by variable resistances in the circuit. Thus, suppose a circuit made up of a

cautery burner whose resistance with its leads amount to ·01 ohm, and an accumulator whose electromotive force is two volts and internal resistance ·002 ohm; the current would be well governed by having a variable resistance up to ·5 ohm in the circuit. When the current was turned on with full resistance it would amount to about 3·9 ampères, and by reducing the variable resistance to ·088 ohm, a current of 20 ampères would be given which would probably suffice to heat the burner.

It must be borne in mind that a resistance, suitable for regulating small currents, may be burnt and destroyed if large currents are allowed to traverse it, also that a resistance of one or two ohms may be ample for regulating a lamp or cautery, but will exercise no appreciable regulating effect upon a circuit of high resistance. In general a rheostat should have a resistance approximately equal to that of the circuit which it is to control.

FIG. 49.—Adjustable resistance for medical use.

With resistances for medical treatment it is more important to have a resistance which can be smoothly adjusted and varied while the current is passing, than one which is graduated exactly in ohms.

An useful form of adjustable resistance is shown in fig. 49, where a movable arm is made to touch successively upon a series of metal studs which are connected behind to a resistance whose value is shown by figures marked opposite the studs.

A form of resistance coil that will frequently be found useful is one which is known as the "wire rheostat." It is very convenient in cases such as the example given above, in which there is a small external resistance only in the circuit, and a

large current is to be regulated. It usually consists of a long coil of moderately thick uncovered German silver or other wire, of high specific resistance. The current is led in at one end of the helix, and a metal traveller sliding on a metallic arm from end to end of the coil forms the other terminal. The resistance interposed is easily seen to be proportional to the number of turns of the wire between the end attached to the terminal and the sliding piece. The form of this resistance is favourable to

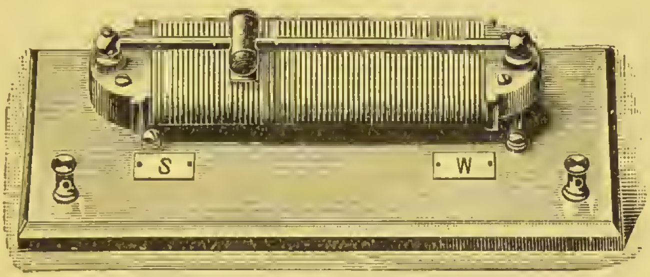


FIG. 50.—Wire resistance with traveller. W, weak. S, Strong.

cooling, thus a much larger current may be driven through it than through a coil of covered wire not open to the air. It is especially useful for regulating the current in cautery or lamp instruments.

80. **Graphite resistances.**—A very handy form of adjustable rheostat for high resistances and small currents is a sliding graphite resistance, figs. 51 and 52. It consists of two parallel

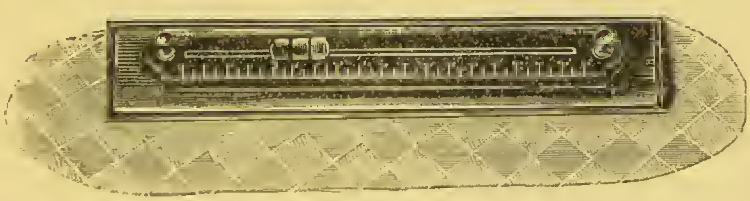


FIG. 51.—Graphite rheostat.

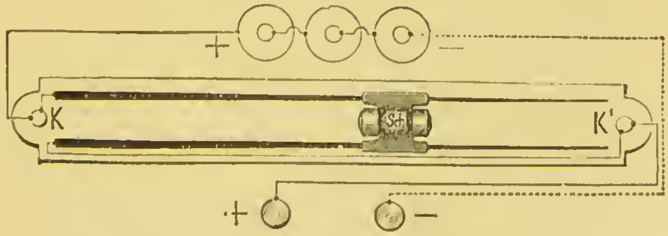


FIG. 52.—Plan of graphite rheostat.

pencils of graphite, with a metal sliding piece moving between them, and in contact with both. As the position of the slide is altered, a greater or less length of the badly conducting graphite is brought into the circuit and the resistance of the circuit is varied thereby. Graphite rheostats are also made up in various patterns.

81. **Liquid resistances.**—Another adjustable resistance apparatus made up in many forms is the "liquid rheostat." It consists of a glass vessel filled with water or some saline solution, through which the current must pass to reach a conductor which is immersed in it. The resistance offered by the liquid varies with the length of liquid to be traversed and the nature of the solution, and the rod can be roughly graduated for the resistance of the liquid to be used.

An ingenious form of liquid resistance is made of two glass

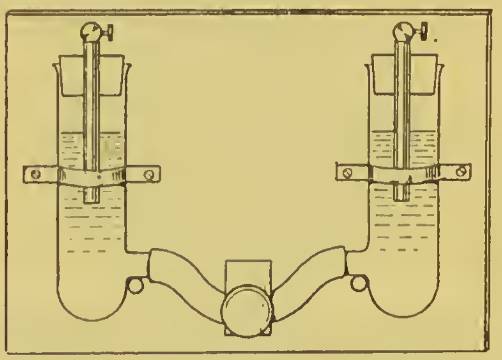


Fig. 53.—Liquid resistance of Guilloz.

vessels connected by an indiarubber tube. The vessels and the tube are fixed to a stand and filled with saline solution. The indiarubber tube is provided with a screw clamp and when this is tightened the lumen of the tube is gradually obstructed, and in this way the resistance of this part of the circuit can be increased progressively until it becomes practically infinite.

82. **Rhythmic interruptors.**—In medical treatment it is sometimes useful to interrupt or to vary the current rhythmically, and several mechanical devices have been invented for slowly turning a current off and on, or for turning it off and on and reversing it as well. Among these may be mentioned the metronome, which has long been used in physiological laboratories for making and breaking contacts in circuits at a slow rate. By a modification of its arrangement the metronome can

be used with advantage in medical treatment, and the method proposed by Leduc* has been in regular use at St. Bartholomew's Hospital for some time with good results.

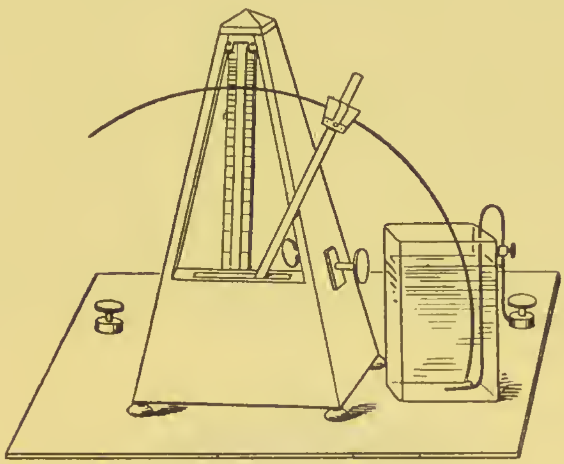


FIG. 54.—Rhythmic interruptor of Leduc.

The metronome (fig. 54) has a curved aluminium rod attached to its moving arm, and as this swings to and fro the rod gradually dips down into a vessel of water, and rises out of it again. At the bottom of the vessel is a wire to which the

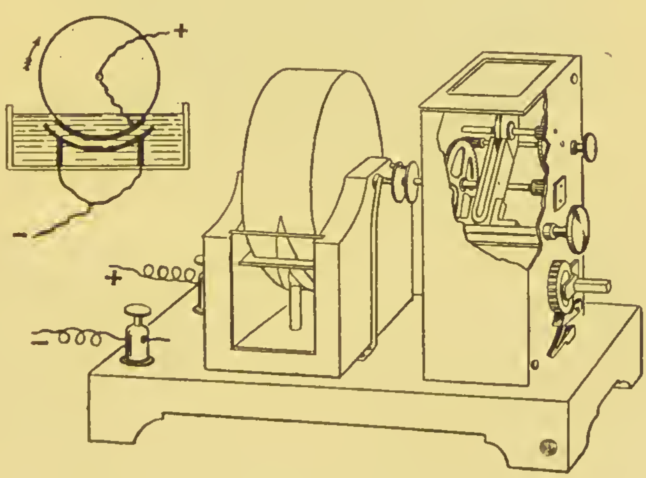


FIG. 55.—Rhythmic interruptor of Bergonié.

current passes. As the moving aluminium rod approaches the bottom of the vessel the resistance of the circuit gradually falls and the current rises to a maximum, decreasing again as the

* *Archives d'électricité medicale*, 1900, p. 300.

extremity of the aluminium rod recedes during its upward movement. The fixed wire is insulated except at its extreme end.

Bergonié* has also devised a convenient machine for producing the same result. It consists of a vertically placed disc of ebonite moved by clockwork and rotating with its lower third immersed in a trough of water. On the edge of the disc is a lozenge-shaped piece of platinum foil which is connected to one pole of the circuit, the other pole is inside the trough of water in a position close under the edge of the disc. As the disc revolves the platinum gradually enters the water and approaches the other conductor, and as gradually recedes from it, and emerges from the water again.

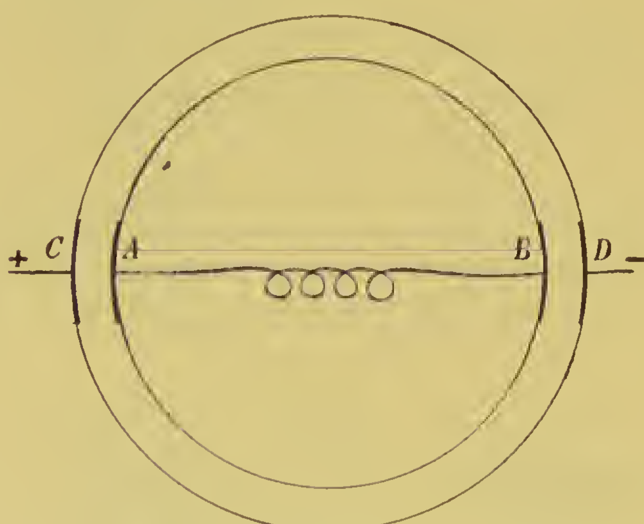


FIG. 56.—Plan of Ewing's rhythmic reverser.

Another method of varying the current in a circuit and also of reversing it is indicated in the accompanying diagram. An insulating drum of ebonite is revolved in a glass cylindrical vessel of water which it nearly fills. There are metallic armatures C D inside the vessel at opposite diameters. Corresponding armatures A and B are fixed to the ebonite drum. If a difference of potential be maintained between C and D, as indicated by the signs + and —, there will be a flow of current from A to B through a conducting circuit joining those points when the drum is in the position shown in the figure, and if the drum is turned round through 180° there will be a flow from

* *Archives d'élect. médicale*, 1896, p. 66 (figures).

B to A, as the positions of A and B relative to the armatures C and D will have been reversed. Thus by rotating the ebonite drum a sinusoidal current will be set up in the circuit A B. It will reach its maxima when the armatures A and B are close to C and D, and will be at zero when they occupy the positions at right angles to this.

This method affords a means of producing slow rhythmic reversed currents which are sometimes required for medical treatment. To utilise the current in the circuit A B it must be collected by means of rings and brushes, very much in the way used with an alternating current dynamo.

83. **Galvanometers.**—The older types of galvanometer are being superseded in medical practice by newer forms of instru-

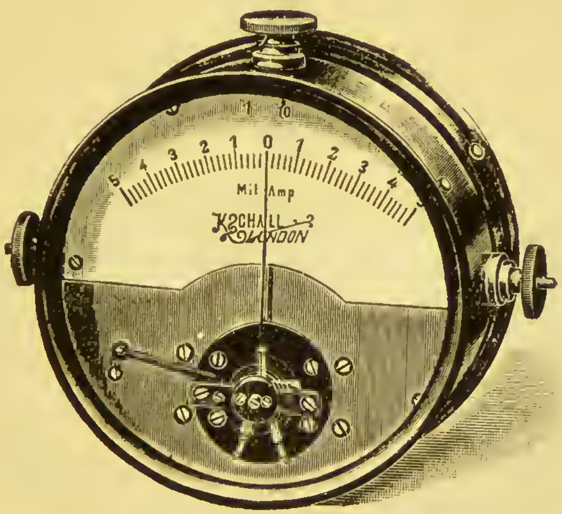


FIG. 57.—D'Arsonval milliamperemeter, with moving coil.

ment of the d'Arsonval pattern, or of some modifications of it. These have the advantage that they can be used either in a horizontal or vertical position. They are independent of the earth's magnetism and therefore do not require to be set in the magnetic meridian, nor are they affected by the proximity of iron or of stray magnetic lines in their neighbourhood. They are also dead-beat, that is to say, the pointer indicates its readings without preliminary oscillations. Thus time is saved and the patient spared the inconvenience of having to bear a possibly painful current while the operator is waiting for the oscillations of the needle to settle down, in order that he may obtain a reading of the milliamperemeter.

In the d'Arsonval instruments the movements of the needle are controlled by placing it in a strong magnetic field between the poles of a horse-shoe magnet. In the modified "moving coil" instrument the magnetic needle is replaced by a slender coil of wire which carries the current, and so acquires magnetic properties (§ 45). It is so suspended as to be free to move, and a spring attachment brings it back to zero again. The general appearance of these instruments is shown in fig. 57. They may

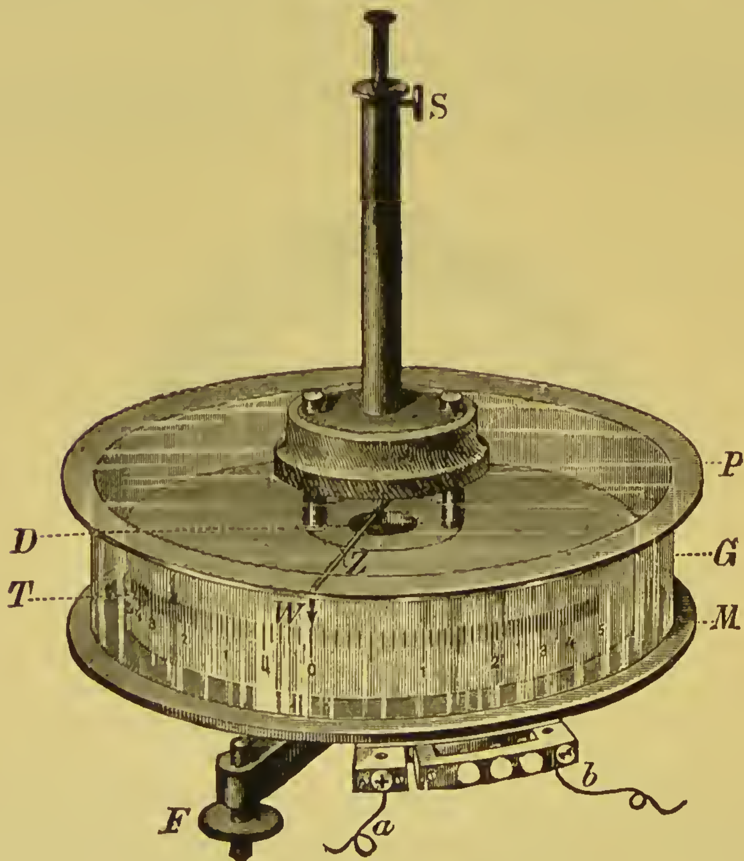


FIG. 58.—Edelmann's galvanometer.

be obtained as milliamperemeters, as voltmeters, and as amperemeters, and can be constructed to read within any range likely to be required in medical practice.

In the case of horizontal galvanometers of the ordinary type, the position which the needle takes up when a current is flowing through its coils, is the resultant of two forces, viz., the attraction of the earth's magnetism tending to hold the needle in the magnetic meridian, and the attraction of the field of force

of the coils tending to draw it into a position at right angles to this. Changes in the magnetism of the needle do not alter the relation which the two opposing pulls bear to one another, and therefore the deflections of the needle are not altered if the magnetism of the needle becomes diminished, as may be the case with the lapse of time. This makes the horizontal galvanometer trustworthy for use as a standard instrument.

Before use, all horizontal galvanometers must be so placed and levelled, that the needle comes to rest at the zero of the scale, and swings freely about that point. The magnetic needle then points along the magnetic meridian of the place where it is to be used.

Fig. 58 is a representation of Edelmann's large non-portable galvanometer, which is very convenient as a standard instrument, although it is tiresome to use in medical treatment as it is not "dead-beat," and time is required to read off its indications. At F is seen one of the three feet of the instrument with its levelling screw; M is the base board, G a short cylinder of glass covered by a glass top, P. The magnet with its pointer, Z, the end of which is seen at W, is suspended by a silk fibre at S. T is the scale, a cylinder of paper divided to read in milliampères. At *a* and *b* are seen the wires which lead the current into and out of the galvanometer, the three small discs between *a* and *b* are the heads of three screws by means of which shunts can be thrown in to reduce the proportion of current passing through the galvanometer to $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$, respectively of that of the whole circuit, so that when one of these is in use the reading of the scale must be multipled by 10, 100, or 1000, as the case may be, to give the whole current in the circuit. In this way the instrument is enabled to give readings over a much wider range than would otherwise be possible.

The arrangement of the shunt circuits is illustrated in fig. 59. Between the binding screws, marked + and −, the galvanometer coils are represented. Two other paths are shown beneath, either of which can be completed at the points of their respective screws; both of them have a lower resistance than the circuit of the galvanometer coils and when closed they convey nine-tenths and ninety-nine hundredths respectively of the current, while the remaining tenth part or hundredth part traverses the galvanometer coils and produces its proper deflec-

tion. But if the deflection is known to be due to one-tenth of the current only, then to get the total current the indicated reading must be multiplied by ten, and the same for the other or 100 times shunt.

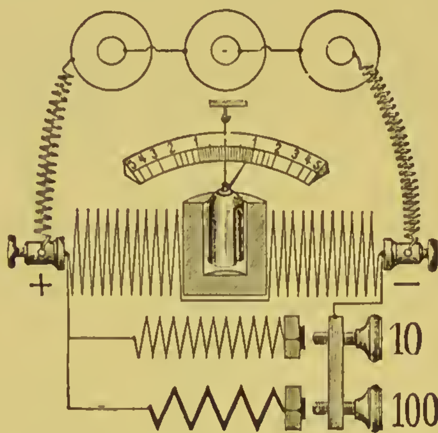


FIG. 59.—Plan of shunt circuits of a galvanometer.

Both shunt circuits are not to be closed at one time.

By means of a battery and a resistance box it is easy to verify the readings of a galvanometer and to determine whether the shunts work properly and correctly.

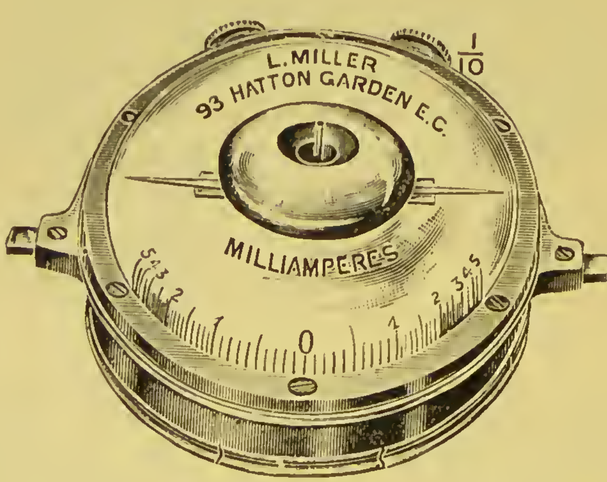


FIG. 60.—Horizontal galvanometer with floating needle.

Fig. 60 shows a form of horizontal galvanometer which is very well suited for medical work. The needle floats in liquid, and therefore moves very readily. Its movements are "damped" by the liquid, which makes it nearly "dead-beat," thus saving

time, and there is no pivot to wear out. It is fitted with a lid, can be carried in the pocket without any risk of damage, is easily connected and disconnected, and so can be used with several different batteries. It is fitted either with one shunt or with two, as may be required.

84. **Ammeters and voltmeters.**—Amperemeters or ammeters are sometimes needed by medical men for measuring larger currents than those for which milliamperemeters are used. In general an ammeter has a very low resistance, and must not be coupled direct to the terminals of an accumulator or to the main supply. The proper way is to connect it in series with the instrument or apparatus whose current it is required to measure.

Voltmeters on the other hand generally have a high resistance, which protects them from overheating unless they are misused. A very convenient way of measuring the electromotive force of a medical battery is to use its own galvanometer as a voltmeter.

Supposing the resistance of the galvanometer to be 25 ohms, and a resistance coil of 975 ohms be connected to the terminals of the battery; the total resistance in the external circuit will be 1,000 ohms.

Now one volt acting upon a resistance of one thousand ohms will cause a current of one-thousandth of an ampère to flow, that is to say one milliampère. With five volts, five milliampères, and so on. The readings of the galvanometer in milliampères will, therefore, express the electromotive force of the battery in volts, if the resistance of the circuit amount to one thousand ohms; any correction for internal resistance of the cells themselves, may usually be disregarded. This method has the advantage of measuring the electromotive force under conditions of resistance like those for which the battery is to be used.

Instrument makers can usually supply a resistance coil properly wound to bring up the total resistance of the galvanometer circuit to a thousand ohms, in order to simplify this mode of measuring the electromotive force of the cells of a medical battery. With this it is very easy to test the voltage of the individual cells, by taking readings of the galvanometer while switching on the cells one after another. Each cell may be taken separately if the battery have a double collector, § 77; if it have a single collector, the increase of reading for each cell

added may be taken to represent its electromotive force. If the resistance coil available do not bring the resistance of the circuit to so simple a figure as 1,000 ohms, the method can easily be used by applying a simple calculation based on Ohm's law.

There are many other types of voltmeter for other purposes. Cardew's "hot wire" instrument consists of a platinum-iridium wire which is heated by the current, and expands, thus moving a pointer which indicates the expansion on a specially calibrated dial. Ayrton and Perry's is a coil or solenoid, which draws a

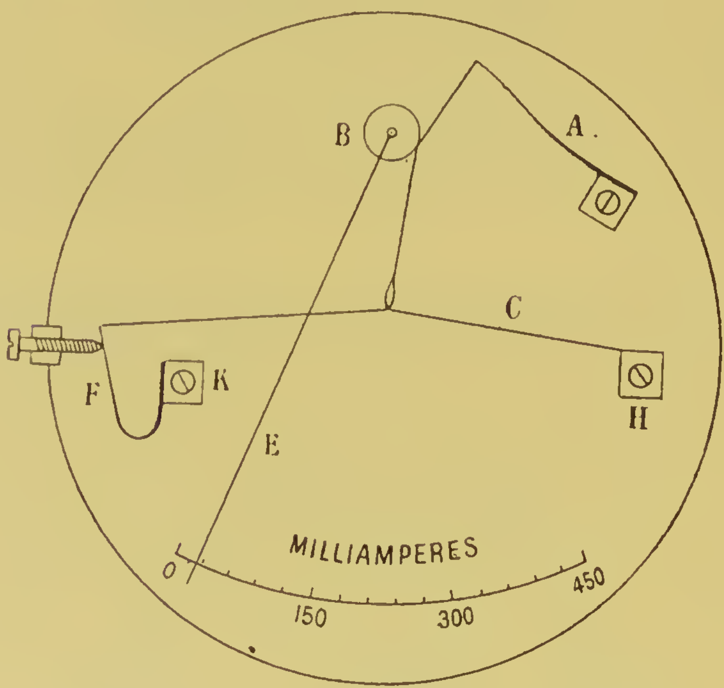


FIG. 61.—Arrangement of "hot wire" instrument.

soft iron core into it, the movement being indicated on the dial by a very ingenious spring. The Kelvin electrostatic voltmeter is an adaptation of the principle of the mutual attraction of oppositely charged bodies. It uses no current, and will read equally well on either continuous or alternating circuits, as also does Cardew's.

Fig. 61 shows the construction of a "hot wire" instrument. C is the wire stretched between H and K by a spring F. A thread attached to its centre passes round B to a spring A.

When the wire expands the pull of A deflects it, and the movement is communicated through B to the pointer E.

85. **Voltameters.**—The testing of a galvanometer by means of a voltameter method, consists in passing a current through the galvanometer and an electrolyte for a measured time, and determining the amount of chemical decomposition which has been produced from this; the current can be calculated and compared with the readings given by the galvanometer. To be of use the method must be carefully carried out, and requires the resources of a laboratory.

In the water voltameter the products of electrolysis are the gases Oxygen and Hydrogen, and these are collected and measured in some conveniently designed apparatus. Ten milliampères of current will liberate 1·056 cubic centimetres of mixed gases in ten minutes. The electro-deposition of metallic silver or copper from their solutions, may also be used for voltametric purposes by weighing the metal deposited after a measured period of time. See Ayrton, "Practical Electricity," Chap. I. and VIII.

86. **Practical note.**—In concluding this short account of medical batteries, we would remind the reader that there are few things so difficult to follow as the connections of electrical apparatus. Probably at first he will find difficulty in making the simplest piece of apparatus work. But he need not, therefore, jump to the conclusion that the battery or galvanometer, or instrument that he is using, is out of order. The connections in the different portions of the circuit should first be examined, and in all probability the fault will be found at one of these. It is a very good thing to draw a diagrammatic plan of them, and to check them off and make certain that all wires are connected up in the intended way. It is of course understood that the values of the various electromotive forces and resistances in the circuit have been so arranged as to give the required effect. If things will not go right, then the electromotive forces of the cells should be taken, and it will be quite time enough to apply to the instrument maker when something has been found to be wrong with these. A little intelligence in the application of theory will often save much cost and trouble in practice.

CHAPTER V.

The Utilisation of the Electric Light Mains.

Regulation of pressure and of current. Use of shunt circuits. Direct current. Applications to patients. Accumulator charging. Operation of large coils. Galvano-cautery methods. Alternating current. Transformers. Accumulator charging. Rectifiers. The aluminium cell. The Nodon valve. Dangers.

87. **The use of the mains.**—Those who live in a place where there is a public supply of electricity are spared the difficulties associated with the maintenance of primary batteries, and only require to know the capabilities of the supply at their command, and how best to adapt it for their professional requirements. For this it is necessary in the first place to know whether the public supply is direct or alternating; secondly, the voltage or pressure of the supply; thirdly, in the case of alternating current, the periodicity or frequency of the alternations. In the Appendix is set forth a list of the public supply stations in Great Britain and Ireland, with particulars of these details. Much progress has been made in the design of medical apparatus for use on electric light mains, and for turning the current to account for medical purposes, whether the system of supply be a direct or an alternating one.

The difference between direct and alternating current is that in the former there is a steady flow of current from the one conductor or lead through the lamp (or other appliance) to the other. The one wire is always positive, the other always negative. In the alternating supply the current flows in a series of pulsations, first in one direction, and then in the other, each wire being in turn either positive or negative. The pressure at which electric lighting currents are supplied to houses is usually 100 volts, in some places 103, 105 or 110. At the present time a gradual change to 200 as the standard pressure of supply is taking place, with the object of saving expense in mains. At 200 volts a given current represents twice as much energy (§ 29) as the same current at 100 volts, so by doubling the voltage of supply,

the conductors are enabled to carry a double load without the need for increasing their sectional area, as would be necessary if they had to carry double the magnitude of current (see § 26 on heating effects of currents). There is no special advantage to the consumer from the higher voltage, but rather the reverse, but the advantage to the supply companies in the saving of capital outlay on copper for mains is considerable.

In the succeeding sections the best ways of managing the current from the mains will be considered in its various applications in medical practice.

First it will be convenient to take the case of a place having a direct current supply (D.C.), and secondly that of a place supplied by alternating current (A.C.).

The uses to which the current from the mains may be applied are as follows:—

1. To replace medical batteries and coils in the treatment of patients.
2. To provide sinusoidal current for purposes of treatment.
3. To charge accumulators.
4. To illuminate the small lamps used in diagnosis, such as cystoscopes, antrum lamps, &c.
5. To heat galvano-cauteries.
6. To work large coils for X ray and high frequency applications.
7. To drive motors for statical machines or for dental and other drills, saws and trephines.
8. To operate arc lamps.

88. **Direct current. Resistances.**—In almost all applications of the current to medical practice the first need is for means of reducing the pressure. The pressure of supply (100 volts or upwards) is too great for any of the medical purposes just enumerated, except for large induction coils and for the driving of some electromotors. In order to reduce the pressure resistances are employed, for by means of the resistances in a circuit the magnitude of the current in the circuit can be regulated. Thus a resistance of 100 ohms in a circuit of 100 volts will prevent the current from exceeding one ampère and a resistance of 100,000 ohms will cut down the current to one milliampère and so on.

It is important to distinguish between the effect of a resistance in cutting down the current in a circuit, and its effect in

lowering the voltage in a circuit or portion of a circuit. In § 33 when treating of the internal resistance of cells an attempt was made to draw this distinction, and it must now be repeated that the effect of a resistance upon the voltage in any part of a circuit is a relative one, that is to say the fall of volts in a part of a circuit such as a resistance, depends upon the resistances of the other parts of the circuit, and may be estimated by comparing the resistance of the part under consideration with the resistance of the rest of the circuit. For instance, take a resistance of 99 ohms interpolated in a circuit of 100 volts, when the resistance of the remainder of the circuit is very small, say, for purposes of illustration, one ohm, then the drop of volts in the resistance will be 99 volts. But if four such resistances be inserted in different parts of the same circuit then the drop in volts at each resistance will no longer be 99 volts, but will be one quarter of that amount, and the fall in the potential from 100 to 0 will take place in four steps of about 25 volts, one at each resistance. It follows from this that a resistance intended for regulating the voltage in any part of a circuit must be made proportional to the resistance of the circuit to be regulated. If the resistance of the part to be regulated is 50 ohms then a resistance of 50 other ohms will halve the voltage acting on it, but a resistance of 50 ohms will not equally halve the pressure if the other part has a resistance of 950 ohms, for in this case the fall in volts at the first resistance would only be one-twentieth of the total electromotive force of the circuit, while the second portion would bear a pressure of nineteen-twentieths of the total. A resistance which is suited for the regulation of the current of a lamp will not serve to regulate current through the human body. In the first case a few ohms will suffice, in the latter several thousand ohms are necessary.

It was stated in § 26 that the energy expended when a current passes through a resistance appears for the most part in the form of heat. Resistances, therefore, become heated when in use, and the heating effects must be carefully borne in mind and the resistances designed to carry the currents they are intended to regulate without excessive heating. A resistance suitable for a current of a few milliampères might be burnt out if a current of one ampère were passed through it. From their cheapness and convenience incandescent lamps are often useful for resistances as they are not injuriously affected even by great heating,

and in almost all resistances for medical use an incandescent lamp of eight or sixteen candle-power forms part of the circuit, being combined usually with a coiled wire resistance which admits of adjustment. On a circuit of 100 volts an eight candle-power lamp will cut down the current to about ·3 of an ampère, a sixteen candle lamp to ·6, while a thirty-two will allow 1·2 ampères to pass. As a rough approximation the resistances of incandescent lamps may be taken as follows:—For 100 volts; an eight candle lamp 320 ohms, a sixteen 160 ohms, a thirty-two 80 ohms. With 200 volt lamps the resistances are double of these, and the currents are therefore halved.

89. **Regulation by shunt resistances.**—The ordinary way of using a resistance is to put it in series with the apparatus to be protected. The whole current then passes first through the

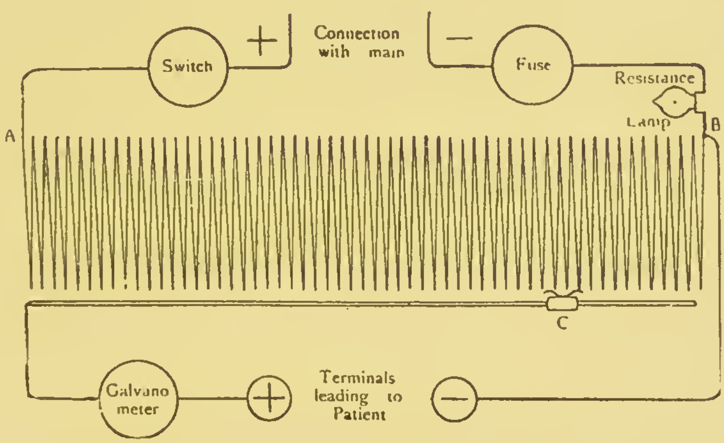


FIG. 62.—Plan of resistance in shunt to a patient.

resistance and then through the apparatus regulated, and for many purposes a simple resistance in series gives all the regulation that is wanted. But another way of using resistances is to have them as a shunt or bridge to the piece of apparatus, the current dividing and passing part by the one channel and part by the other. When two circuits are arranged in this way, in parallel, either of them is said to be "in shunt" to the other, or "shunted by" the other. Arrangements of resistances in shunt to apparatus are often useful, or two resistances may be used in series with each other, the patient (or the piece of apparatus) being arranged as a circuit in shunt to one of them, and fig. 62 shows such a combination of shunt and series resistances. The current from the main passes from the positive pole of the

supply through a switch to A. From A to B is a resistance of wire, and B is a lamp which the current traverses to reach the negative pole, after passing through a fuse. Thus there is formed a closed circuit through the two resistances of the wire coil and of the lamp, with a fall or slope of potential between A and B, and a further fall through the lamp at B, the total fall being from 100 volts to zero on a 100 volt circuit. The circuit for the patient, or instrument, is arranged in a shunt to the wire resistance, and the voltage available in the patient's circuit will be varied by moving the traveller C along its metal slide. Let us suppose that the coils depicted are 450 in number, and that their resistance is nine times as great as that of the lamp B, then assuming our pressure at the main to be 100 volts, the drop of volts in the lamp will be 10 volts, and in the coils 90 volts. With 450 loops in the wire the fall of volts is one-fifth of a volt per loop, that is to say there will be a potential difference of one-fifth of a volt between any loop and the next. If the loops were 4,500 in number then the potential differences would be as one volt for every 50 coils, and so on. The potential difference between C and B through the shunt circuit would increase as the traveller C was moved further towards the A end of the coil, because it would "tap" the slope of potential at a higher level, so to speak, and the more numerous the coils of A and B, the more finely could the volts be adjusted to suit any needs of the shunt circuit.

With certain structural variations, chiefly in the number of the windings and the thickness of the wire, this method will suit all the cases which require a low pressure to be obtained from the electric light mains. The lamp acts as a safety resistance, and determines the maximum current which can pass through the apparatus. A certain latitude is afforded by the use of lamps of various candle-power for that portion of the resistance. When the current is to be applied to the lighting of a small surgical lamp which requires, say, an ampère, the safety lamp must be of such a character as to permit that amount of current to pass it. When a cautery is to be heated no lamp is arranged in series with the coil, and the various parts must be on a much larger scale, because they may have to waste energy at the rate of one horse-power or more when in use, and the current of five, ten, or twenty ampères which a cautery requires, has considerable heating effect upon the wires which lead to the cautery, as

well as upon the cautery burner itself. The whole apparatus, therefore, becomes heavier and more expensive to make. The immediate application of a direct current from the mains to the commoner requirements of medical practice is fully met by a set of resistances arranged to give slopes of potential, with arrangements for tapping it at different points for the shunt circuits in which the patient or the apparatus is arranged.

In shunt circuit regulation energy is continuously wasted, because a steady flow of current along one of the two conducting paths is necessary, in order that the flow along this path, which may be called the regulating circuit, shall provide the gradual fall or slope of potential which is to be tapped for the other or utilisation circuit.

It might be thought that regulation of current in the ordinary way by resistance in series with the patient would be sufficient for general medical purposes.

For instance, if it were wished to apply a current of 5 or 10 milliampères (·005 or ·01 ampère) to a patient from a 100 volt main, this could be managed by a cheap graphite resistance of 20,000 ohms, reduced gradually to 10,000, but the effect upon the patient would be more disagreeable than that which he would experience with the same current from a source of electricity at a lower potential. If the resistance of the skin is high, as is frequently the case, it will be subjected to a needlessly high electromotive force until it has become well moistened, instead of being gradually coaxed down by a low pressure, as happens in ordinary treatment when the E.M.F. of the battery is slowly raised by adding cells to the circuit until the required current is obtained. A time-element, therefore, comes in, and unless extra care be expended in reducing the skin resistance by a preliminary soaking or thorough moistening of the skin, treatment of the kind indicated from the electric light main through a resistance in series is apt to be unpleasant. On the shunt circuit this is not the case, for the operator commences his test or his treatment with a low electromotive force, which he can gradually raise as high as may be needed, so that the abrupt application of a high voltage to a badly conducting skin surface is avoided.

90. **Shunt circuits for heavy currents.**—When large currents are required, the advantages of a shunt circuit over regulation by resistances in series becomes even more evident

for certain applications. In the case of a galvano-cautery requiring ten ampères to heat it, the current from the 100 volt main could be choked down to the required magnitude by a resistance of ten ohms in series with the cautery instrument, but to use it in this way would be positively dangerous. Ten ampères of current is quite sufficient to maintain an electric arc across a small air gap, and it might easily happen that on breaking the circuit in the usual way with a key in the handle of the cautery instrument, an arc might be established at that point, which would instantly destroy the handle. Or again, if from any cause the platinum of the cautery should break or fuse during its use, the establishment of an arc, with an accompaniment of drops of fused platinum and copper in contact with a patient, might have serious consequences.

The risk of such an accident can only be avoided by having two parallel circuits from the positive to the negative main, one

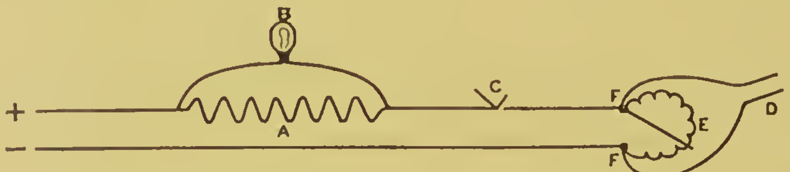


FIG. 63.—Arrangement of circuits for cautery on continuous current mains. D. Utilisation circuit. E. Shunt circuit.

to carry the cautery and the other to act as the shunt circuit in case of accidental fusing or fracture of the cautery wire. No arc need then be feared, the only drawback being that the apparatus expends energy at the rate of about two-horse power while it is in action, and special main wires and fuses are required to carry the current. As each branch may have to carry upwards of ten ampères when the cautery is at work, they must be constructed in a substantial manner to stand that magnitude of current.

A diagram of the connections is as follows:—A on the positive main represents a strongly made resistance of about five ohms. B is a red lamp which serves as a signal when the current is on. C switch. D wires to cautery. E shunt circuit, its exact resistance being varied by the moving arm, which is used as the regulator (fig. 63).

With this apparatus a current of about 20 ampères traverses the circuit when the switch is on. At F F the current divides,

passing either through a resistance E, or through both E and the cautery D. The amount going by each route is adjusted by the moving arm, which can travel along E.

In this way the tendency to an arc is got rid of, and there is very much less sparking and burning at the contact in the handle of

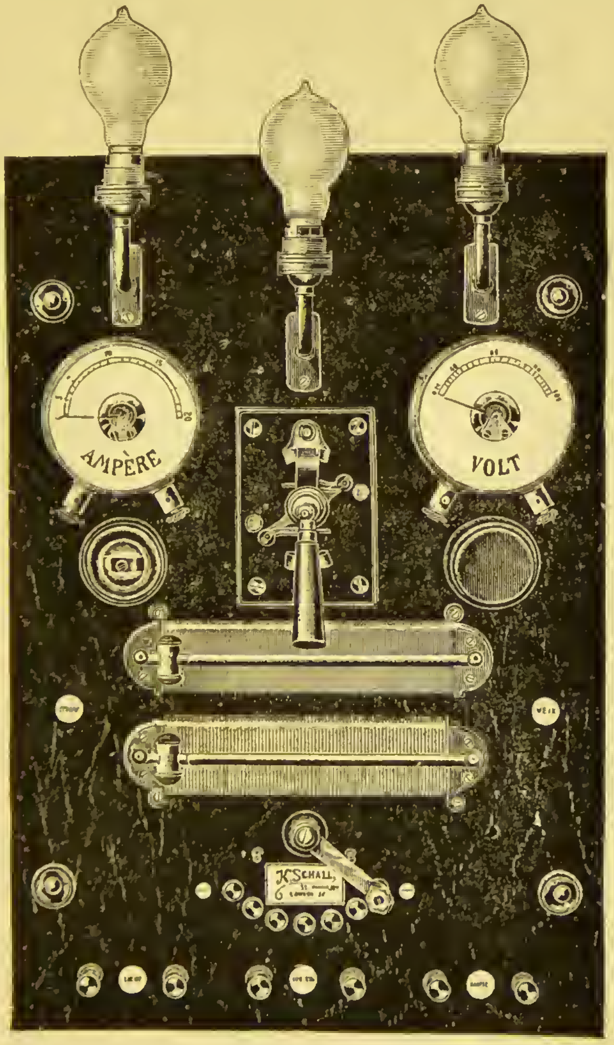


FIG. 64.—Shunt circuit resistance for large currents.

the cautery. A red lamp burns whenever the current flows, so that there is no excuse for wasting current.

So again in the case of Rhumkorff coils worked from the mains. From a shunt circuit pressures of 20, 30, or 40 volts can be applied at the terminals of the coil, and the sparking at the contact breaker is very much less than it would be with the

same current cut down by a resistance in simple series. In the latter case the spark is almost explosive in its violence, so much so that only the most rapid breaks can be used to operate large coils direct upon the mains without shunt circuit regulation.

Shunt circuit instruments for use with heavy currents are made as a rule of a number of open coils of thick iron wire affixed to the back of a slate or marble slab with ample air spaces for ventilation, by which means the heat generated in the coils is dissipated. The coils are joined together in a series, and at intervals a connection is led off to a stud on the front of the switch board, whence the current is taken to the appropriate binding screws through a moving crank arm, or else connections are made to one of a number of separate plug sockets for the different circuits of utilisation (fig. 64).

A lamp is often fitted to the switch board to indicate that the current is on through the coils. This is useful in order to prevent unnecessary waste. The coils of wire form a closed circuit, and according to the number, length and thickness of the iron wire coils the flow of current through them may be five or ten ampères or more. A voltmeter and amperemeter and a safety fuse are added, and in some cases an adjustable resistance for further regulation in the utilisation circuits is used to make the switch board complete.

It will be seen in the succeeding sections that series resistances suffice for some purposes, although for others a regulation by shunt resistances is absolutely necessary.

91. **D.C. Applications to patients.**—A simple switchboard on the shunt resistance principle is shown in fig. 65. It can be used for direct applications of "galvanic" current to patients, and has a pair of terminals for attachment to an induction coil for generating "faradic" currents. It can also be used for charging an accumulator.

More ambitious outfits are manufactured, and an illustration of one of these is shewn in fig. 66, which represents a fitting for a wall, with resistance and pilot lamps, slope of potential for shunt regulation, milliamperemeter, induction coil, commutator switches, and box to hold cords and electrodes. Similar outfits are made in stationary cabinets; also on moveable tables, and in desk form for convenience in transporting to and from the bedside.

For the design of these pieces of apparatus, the profession is

largely indebted to Dr. Milne Murray, who undertook the task for the equipment of the Edinburgh Royal Infirmary with proper electrotherapeutic appliances.

The induction coils supplied with these ready made outfits are not very satisfactory. For the sake of providing a sliding core they have interruptors moved by a separate electro-magnet,

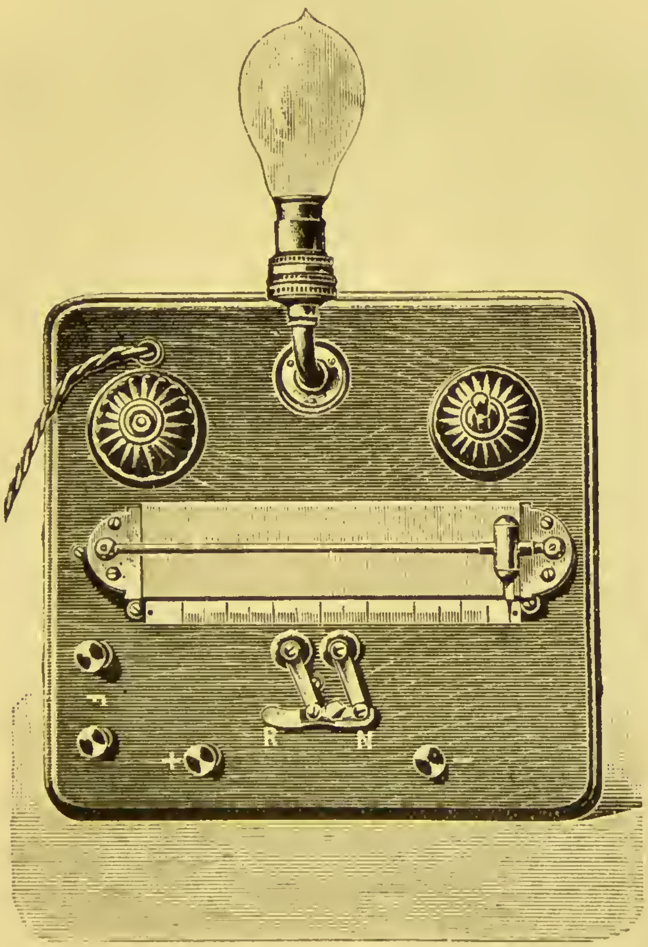


FIG. 65.—Resistance instrument with adjusting slide and commutator.

and they give slow and irregular shocks. It would be better to use a more rapid interruptor worked by the fixed core, and to regulate the "primary current" by a small resistance. Or possibly it would be better to abolish the coil altogether and replace it by a small D.C. motor, fitted with a commutator by means of which the D.C. current could be changed into an interrupted

current, or into a rapidly reversed current. This might overcome the difficulty of the measurement of induction coil currents.

Another point requiring attention with these switch-boards is

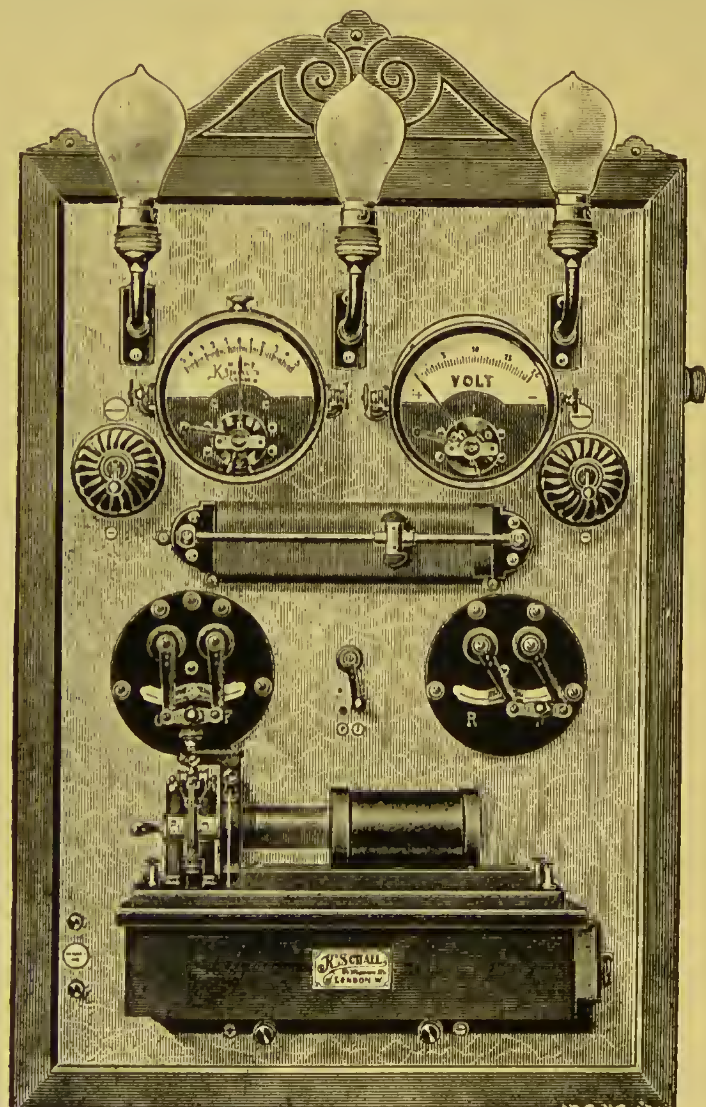


FIG. 66.—Complete fitting for utilisation of direct current mains for medical uses.

the milliamperemeter. This must be protected from short circuits as these would be very likely to overheat and destroy the windings of the galvanometer coils. Dr. Milne Murray has attempted to obviate this by providing the milliamperemeter

with a short circuiting key, which is to be removed only during actual measurements of current.

92. **D.C. Sinusoidal current.**—A direct current motor may

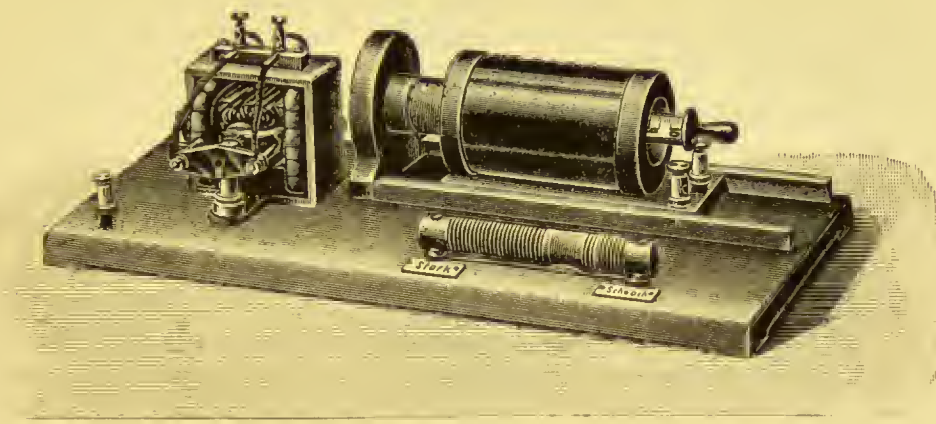


FIG. 67.—Small motor-transformer for producing single phase sinusoidal currents, with transformer to control the strength of the sinusoidal current.

be made to yield alternating current by tapping the armature windings at two diametrically opposite points and leading out connections from these points to a pair of rings insulated from

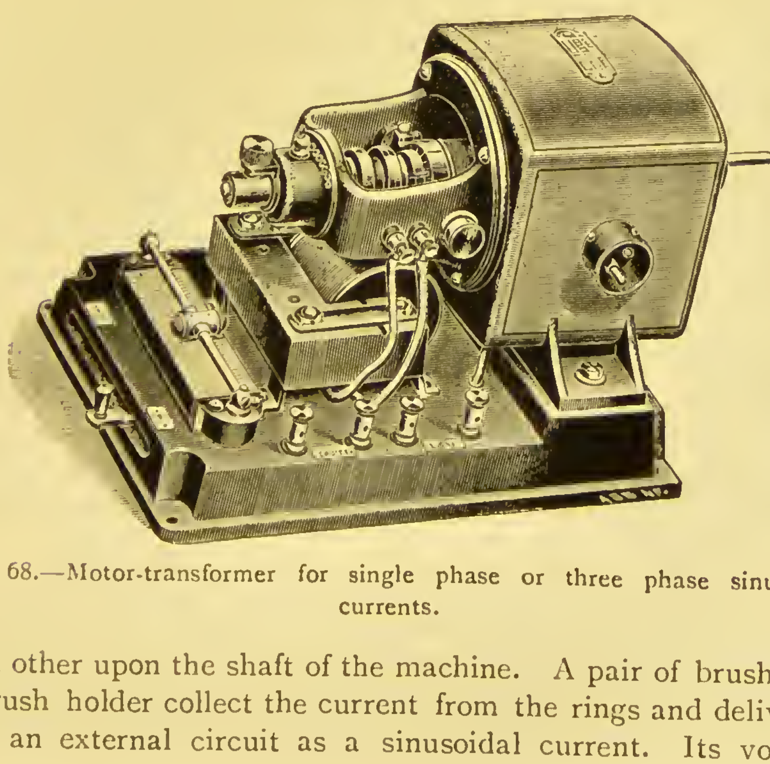


FIG. 68.—Motor-transformer for single phase or three phase sinuosidal currents.

each other upon the shaft of the machine. A pair of brushes in a brush holder collect the current from the rings and deliver it into an external circuit as a sinusoidal current. Its voltage

can then be transformed up or down to suit the applications for which it may be required.

The transformer, if carefully made, serves also to protect the alternating current circuit from any leakage into it from the direct current side of the machine. As sinusoidal current is especially used in conjunction with electric bath methods, where leakages to earth are probable, this precaution is an important one. Leakages of direct current to earth through a patient immersed or partly immersed in water may prove fatal, as a patient under these conditions is deprived of the protection usually afforded him by the resistance of his dry skin and his clothing.

The use of D.C. mains to generate sinusoidal current is not limited to the applications of the latter to patients. For some indirect applications of electricity, especially for lamps and galvano-cauteries, the object desired is best obtained by using a motor-transformer to convert D.C. into alternating current for the sake of the facility with which A.C. can be adjusted for these purposes by means of a transformer (see below, § 99).

93. **To charge accumulators.**—It is often useful to use the direct current to charge accumulators, which can then be detached from the mains and used independently, as for example for providing a portable apparatus to take to a patient's house. Although a desire for absolute uniformity of practice, or the idea of saving one's self trouble, might make one wish to use current from the mains only, without any accumulators, the advantages on a practical side all lie in a combination of the two methods, that is to say in the use of accumulators for some purposes, and in direct applications of the current from the mains in others. Thus by far the simplest way, and the cheapest, for lamp and cautery work, is to charge a portable accumulator from the mains, and then to use it detached for the lamps or cautery. Many surgeons only use electricity for these purposes and with a small portable accumulator and a plug arrangement for recharging it, they can be fully equipped at a small outlay.

To charge an accumulator from the direct current mains is easy. A plug fitting of special construction with a lamp is needed. The current passes through the lamp to the accumulator, as shown in fig. 70, the lamp serving as a protecting resistance. The accumulator is connected by wires to the two

binding screws as shown in fig. 69. To charge from a concentric wall plug, or from an Edison-Swan screw lamp socket is best,

FIG. 69.—Lamp resistance for charging secondary cells from the mains.

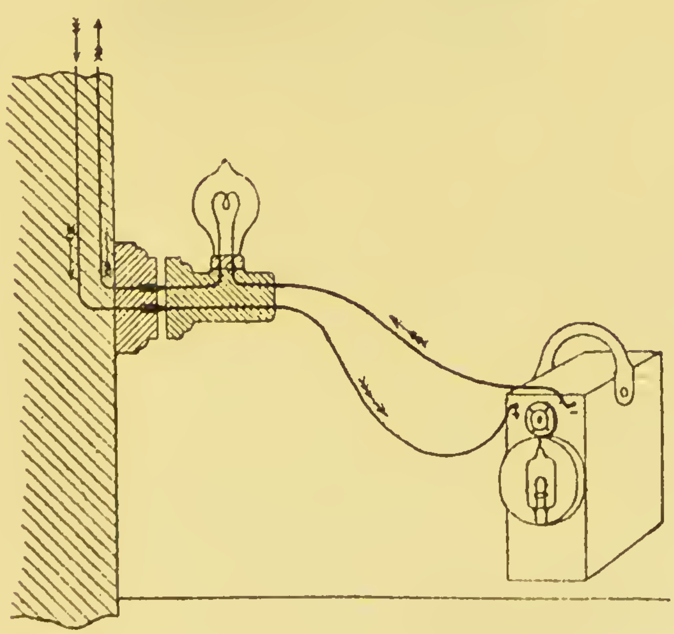


FIG. 70.—Charging an accumulator from the electric light mains.

because such a plug can only fit into its socket in one way and the positive and negative terminals are always the same. With

a lamp socket or a wall plug of the ordinary pattern there would be a right and wrong way and the polarity of the terminals must be tested each time (see § 74, pole testing). A rough and ready way to test the direction of the current when charging secondary cells is to notice the brightness of the lamp when the accumulator is coupled in, for when joined correctly for charging the brightness of the lamp is lessened, whereas the lamp glows more brightly when the connections through the accumulator permit of its discharge. If the experiment of connecting up in each direction be tried a few times the difference in the brightness of the lamp will soon be appreciated.

Arrangements of lamps for charging purposes can be had with 2, 4, or more lamps joined up in parallel and mounted on a board (see fig. 71).

FIG. 71.—Lamp resistance for accumulator charging.

When the charging of the cells from the mains is to be done frequently, it may be worth while to have the charging terminals connected to some one of the house lamps which is in regular use, in order not to waste energy. As the electromotive force of the cells which are under charge is opposed to that of the charging circuit, the lamp will be dimmed to a certain extent by the counter-electromotive force of the cells, this can be met by using a lamp of lower voltage. Thus on a 100 volt circuit, a 90 volt lamp in series with an accumulator of four cells (8 volts) would be brought to full incandescence, and would give a good light while the accumulator was being charged.

94. **D.C. Small lamps.**—From what has been said in the section on charging accumulators (§ 93), it will be recognised that the use of a small portable accumulator presents distinct advantages for use with incandescent lamp instruments. They may also be operated quite easily from the mains by reducing

the current in a simple series resistance. This may be entirely of wire, or partly of wire with an ordinary Ediswan lamp included in the circuit for purposes of economy. The lamp is a cheap form of resistance, and offers a convenient way of dissipating the energy which has to be wasted, but in cases where its light would be inconvenient, a lamp of red or blue glass or else a resistance composed wholly of wire may be used. The lamp chosen must allow the passage of a current sufficiently large to bring the smaller surgical lamp to incandescence. By reason of their relatively thick filaments, some of these small lamps may need a larger current than a full sized 16 candle-power lamp. The disproportion in the amount of light given out is due to the difference in length of the filaments in the two cases; and this is a matter of volts and not of current. Small lamps may also be lighted by a motor transformer, as indicated at the end of § 92.

95. **D.C. Galvano-cautery work.**—There are many ways of applying the D.C. mains to galvano-cauteries.

The simplest, by far, is to charge an accumulator, and to use that for heating the cautery. This has the advantages of portability and of cheapness.

Another way is to use a shunt circuit apparatus (§ 90). This consumes a great deal of current, and may require the provision of special mains, especially if large sized burners are likely to be wanted. Once installed, this plan requires little or no attention to keep the apparatus efficient.

Another plan of procedure is to convert the high pressure current of the mains into a low pressure current, by one of the following methods:—

First, by the use of a motor-dynamo fitted with two distinct windings on the armature, the one to receive a small D.C. current at 100 or 200 volts, and the other to give out a large current, also D.C., at 10 volts. The latter can then be regulated to suit either cautery or lamp instruments, by means of a small and inexpensive series resistance.

Another form of motor-dynamo or motor-transformer converts the direct current into alternating, and this is subsequently transformed to suit the requirements of cautery or lamp instruments (fig. 68).

A third apparatus resembles an induction coil, and is fitted with a platinum interruptor, but its function differs from that of

an ordinary induction coil, because it increases the current at the expense of the electromotive force, whereas a coil is generally used to do the opposite. It is an ingeniously contrived apparatus, and much to be preferred to the shunt circuit apparatus with heavy wires, described in § 90.

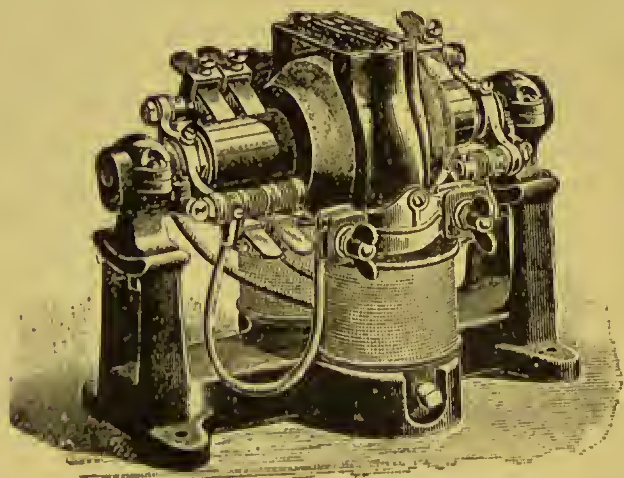


FIG. 72.—Motor dynamo. Two sets of windings upon one armature.

96. **D.C. Rhumkorff coils.**—These may be driven from the direct current mains in several ways. In the first place accumulators may be charged, and these employed to operate the coil, using a hammer interruptor and six, eight, or ten accumulator cells (12-20 volts). This arrangement is transportable, and will be used chiefly when the X rays are required at the bedside, or in a patient's house. Secondly, the mains may be used at their full pressure to operate some form of motor-driven interruptor, as for example, the "dipper" type, or that of Mackenzie Davidson, the exciting current for the coil being drawn from accumulators, in which case sixteen or twenty cells (32-40 volts) may be utilised with advantage. Or instead of the accumulator cells the current of the main can be used, its pressure being reduced by the shunt circuit resistance method described in § 90, or better still, the full pressure of the mains may be used direct through a high speed break. The turbine break of Max Levy, in one of its improved forms, is the best one to use, for by attention to details of speed, of interruption, and of duration of contact, it may be used direct on the mains, without the need of any expensive shunt resistance. Inasmuch as simplification of apparatus is of the first importance in all electro-medical work,

the combination of a rotary break driven by the D.C. main, with direct application to the coil of the full pressure of the mains, is the best outfit for work with large coils.

97. **D.C. Motors.**—The variety of motors for use on D.C. circuits is great. It is best to use one wound for the full pressure of the mains so as to simplify regulation, and to avoid the trouble and expense of providing current at lower pressures. A simple resistance usually suffices for speed regulation, and should always be reduced gradually in starting.

For instruments whose movement must permit of sudden stoppage, a switch is designed for cutting off the exciting current, and for short circuiting the motor windings at the same time by connecting the commutator brushes. This has the effect of converting the motor, temporarily, into a dynamo with a current of large magnitude passing across the brushes. This acts as a heavy load and stops the movement of the armature by absorbing its kinetic energy.

A little attention given periodically to the commutator and the brushes of a motor, will be well repaid in the smooth and equable running of the machine.

98. **D.C. Arc lamps.**—The arc lamps used in therapeutic work are usually fitted with proper resistances for smooth working upon direct current supply circuits. They will be considered in a separate chapter on the application of light radiations to medical practice.

Under certain conditions the direct current arc affords a means of producing alternating currents of very high frequency. These may, some day, be applied to medical practice. See Duddell on "Rapid Variations in Current through Direct Current Arcs," *Journal of the Institution of Electrical Engineers*, vol. 30, pp. 232-267, and Wertheim-Salomonson, *Archives d'électricité médicale*, 1902, p. 568, and 1903, p. 550.

99. **Alternating current. Transformers.**—The main feature of convenience which alternate currents have, lies in the ease with which they can be made to induce fresh alternating currents at any desired voltage. With continuous currents, as we have just seen (§ 88), the voltage of supply can be cut down by means of resistances, which may also be used with alternate currents, but by means of a transformer the pressure of supply of an alternating current can be changed into any other pressure, higher or lower, as may be desired, and that

without the waste of energy which occurs in the case of resistances. Thus by a transformer the energy represented by a current of one ampère at 100 volts can be transformed into a current of 100 ampères at one volt, or into a current of one-hundredth of an ampère at 10,000 volts, subject only to small losses in the apparatus. Whenever the alternating pressure of the mains is higher than may be required it can easily be reduced by the use of a transformer, and this should always be borne in mind in medical applications.

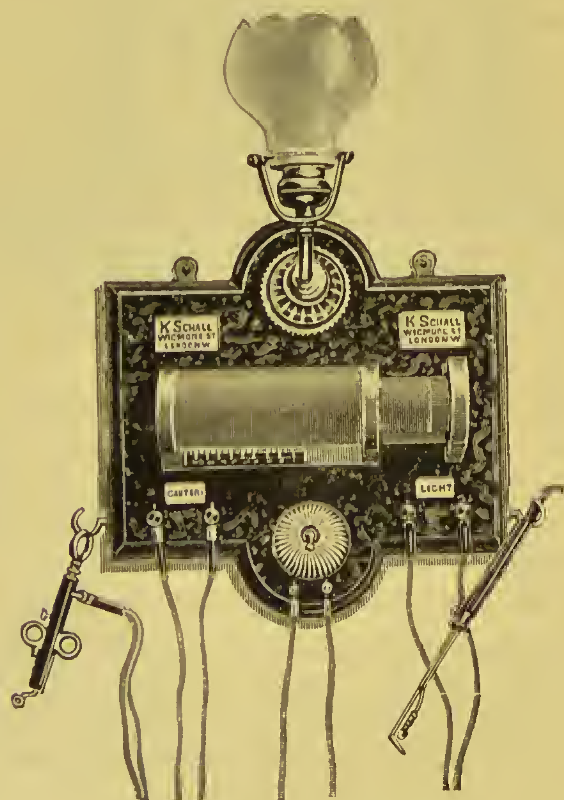


FIG. 73.—Woakes' transformer.

The principle of the transformer is that of the induction of a current in a wire by a variable current in a neighbouring wire (§ 52), and the transformer consists of an iron core wound with two distinct windings of insulated wire. These may be called the primary and the secondary windings, and the variable E.M.F. impressed upon the primary when it is connected to a system of alternate current supply will induce, in the secondary, a variable E.M.F., having a value which will depend upon the ratios of

the number of turns of wire in the primary and secondary coils.

The commonest type of transformer for medical use is one which is used to convert a small current at 100 volts into a larger current at two or four volts for cauteries, or at eight or ten volts for small incandescent lamps, or for use in the electric bath, while, occasionally, transformers may be required to give out high pressures of some thousand volts for generating ozone, or for working Tesla high frequency coils.

The first transformer specially designed for medical use is Woakes' transformer, which dates from 1891. It has several secondary coils all wound upon one bobbin; one for cautery to give about four volts, and wound with thick wire to carry a heavy current without heating; one for small lamps, and one

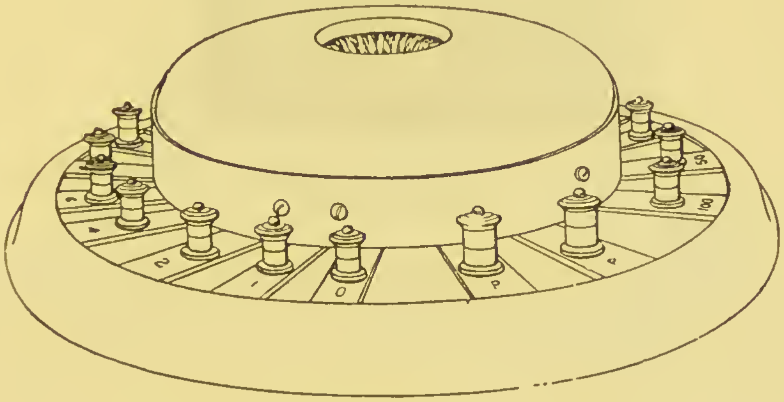


FIG. 74.—Transformer graduated in volts.

for therapeutic purposes. Each secondary has its own terminals, and all are excited by one primary coil. Regulation is effected by a sledge coil arrangement, which serves to bring the secondary coils towards the primary coil, or away from it. In other forms of medical transformer the iron core is not straight as in Woakes' pattern, but is a circular ring of laminated iron. This is more efficient electrically, but less convenient for regulation. Fig. 74 shows a ring transformer, which has a secondary tapped and brought out to binding screws at intervals, thus affording a means of obtaining different known voltages from one instrument. Other medical transformers are made with a moving arm, which takes up into circuit more or less of the windings of the secondary, and so gives very good regulation of pressure.

In other forms of transformer the final adjustment of voltage is obtained by sliding resistances, the transformer being provided with one or more secondaries, so wound as to give approximately the pressure likely to be wanted from it (fig. 75).

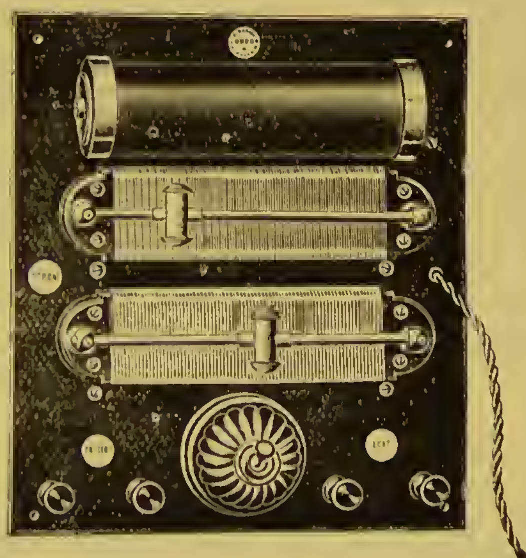


FIG. 75.—Transformer, with two sliding resistances, for cautery instruments and for small lamps.

100. **A.C. Conversion into direct current.**—For some medical purposes the alternating current is unsuitable, and a means of obtaining direct current from the alternating supply may be much desired, and the following plans have been proposed for this purpose:—

1. An alternating current motor may be used to drive a D.C. dynamo. These may be coupled by a belt, or may be built upon one shaft, or finally may consist of two sets of windings upon one framework, provided the motor side of the machine be suitably designed, and proper excitation of the field be provided for.

In either case there is a conversion of electrical into mechanical energy, and a reconversion of mechanical energy into electrical again. The method gives wide choice on the generating side, as to the pressure and magnitude of the generated current, up to the limits of the energy expended on the motor side.

2. A rotary converter may be used. A pair of rings with collecting brushes is fitted on the axle of a D.C. motor. They

are insulated from the shaft and from each other, and are connected to two opposite segments of the commutator. If the machine can first be speeded up into synchronism, it will run smoothly as a motor when fed with alternating current through the brushes to the rings, and will give out a steady direct current from the brushes of the commutator proper.

The difficulty with this apparatus is the starting up to synchronism of the motor, moreover the small machines likely to be used in medical practice are somewhat sensitive to changes of load, and they may be thrown out of step at a critical moment, and stop. The starting difficulty is not insuperable; it may be overcome either by a hand wheel, or by running the machine up to speed as a D.C. motor with current supplied to the commu-

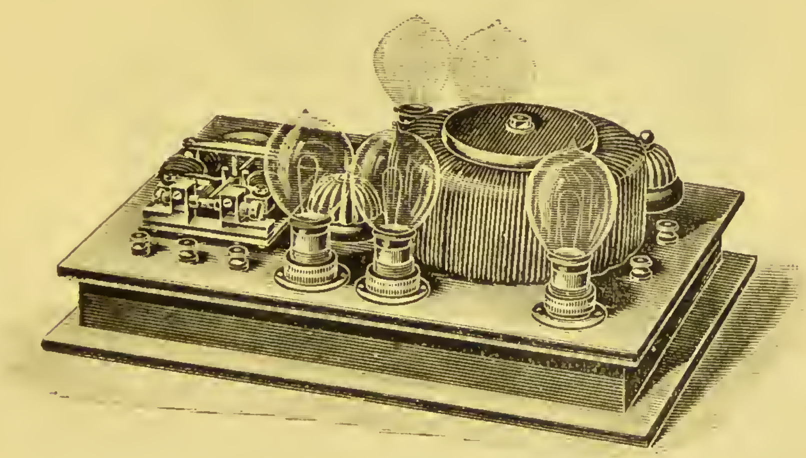


FIG. 76.—Batten's rectifier.

tator from accumulators, which are cut off again when the motor is in step. They can of course be recharged from the rotary converter when it is in action.

3. A mechanical rectifier may be used, and by this is meant an instrument which periodically makes contacts, closing the circuit at such intervals of time as to transmit the impulses passing in one direction, while arresting or diverting those impulses which would tend to pass in the opposite direction. A rectifier, therefore, does not give a smooth flow of direct current, but a series of distinct impulses which all pass in the same direction. This may be quite as useful as a steady current for some purposes, but less so for others.

There are several rectifiers in use among medical men, though

none have come into very extensive use, because of the greater convenience of the chemical or electrolytic rectifier, to be described immediately. Batten's rectifier consists of a short steel rod magnetically polarised, and moving on a pivot between the poles of an electromagnet fed by an alternating current. It is attracted by each pole in turn, as the direction of the current changes, and in its excursions it makes contact with each of two studs, and so closes the circuit of utilisation. It is so arranged as to permit of the utilisation of both semi-periods of the alter-

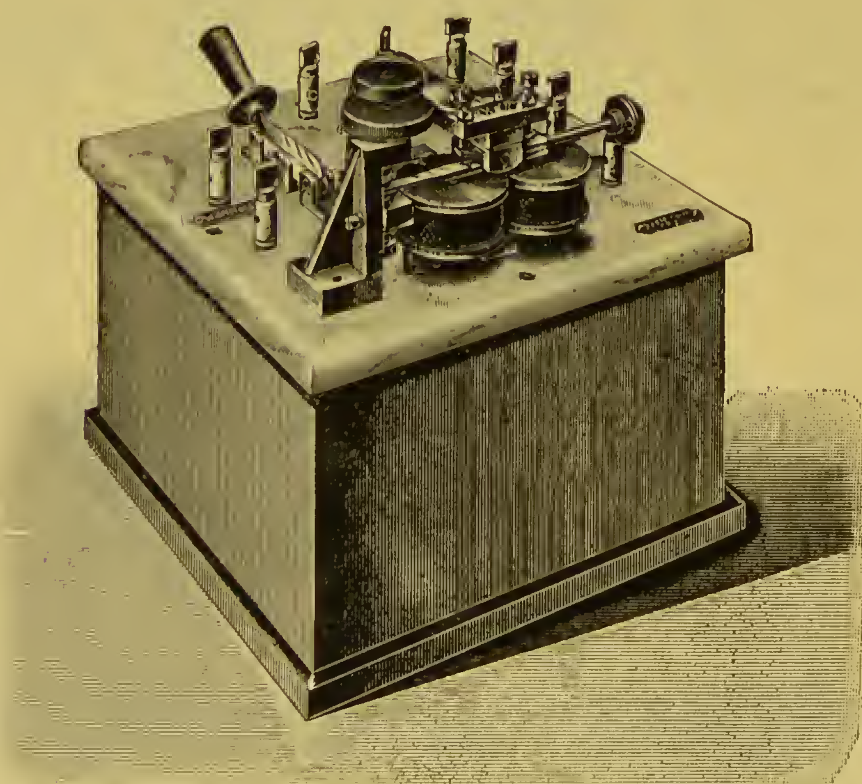


Fig. 77.—Siemens Brothers' rectifier.

nating current, so that, for example, two sets of accumulators can be charged simultaneously.

A very ingenious detail of Dr. Batten's rectifier, is the use of a tinfoil condenser to accelerate the phase of the magnetising current, and of a self-induction to retard that of the current in the rectifier circuit. This device reduces the sparking at the contacts, and is valuable on that account. Another valuable feature of the Batten rectifier is that the pressure of the mains

can be reduced to any required value by a transformer before rectification. This is economical and often useful otherwise.

An apparatus of the same type on a larger scale is made by Messrs. Siemens Brothers for charging accumulators, or for driving large induction coils. In the latter case the contacts are arranged to take place near the tops of the alternating current waves, and the contact surfaces of platinum are massive to carry large currents. In this form the instrument serves at once as rectifier and as interruptor, and makes the operation of coils from the A.C. mains a simple matter. Dr. Batten has proposed to employ his rectifier in the same way, and the rectifying interruptor of Villard is a similar device which is in use in France.

The rectifiers just described work by means of a vibrating tongue, which oscillates in synchronism with the periods of the alternating current. Other types of rectifier operate by means of a revolving commutator fixed on the axle of a synchronous motor.

The rectifier of Dr. Reginald Morton is a beautifully made machine of this type, with a self-starting mechanism for bringing the motor into synchronism. It has a massive commutator, and is able to rectify currents of large magnitude in a very perfect manner. It is made by Messrs. Newton, and the same firm also make a small motor fitted with one or two cranks on the axle. These carry plungers making contact with mercury cups, as in the dipper break (§ 70), so that the instrument serves at once as rectifier and as interruptor for working large coils. It starts easily into synchronous movement with a touch from the finger.*

101. **A.C. Electrolytic rectifiers. The aluminium cell.**— This is a most valuable contrivance for obtaining direct currents from the alternating mains. It is far more suitable for medical purposes than any mechanical rectifier, and it has no moving parts. Its value depends upon a peculiar behaviour of aluminium, by which it offers a very high resistance to the passage of a current when it is made the anode of an electrolytic cell, although as kathode it offers no such resistance. Accordingly an electrolytic cell having aluminium for one pole, and carbon or a metal for the other pole, will tend to arrest the passage of an alternating current through it in one direction, while readily

* *Archives of the Röntgen Ray*, April, 1902 (description and figure).

permitting a flow in the other direction. This property of aluminium has been known for many years, having been discovered by Buff in 1857. Its practical application to alternating currents was suggested by Graetz, Pollak, and others, nine or ten years ago, and since that time the aluminium cell has been extensively studied, and very much improved for practical purposes.

A simple aluminium cell can be made of a plate or rod of aluminium immersed in a jar of ammonium or sodium sulphate solution, with a lead plate for the other pole. With such a cell arranged in series with a resistance, as for example, with a lamp

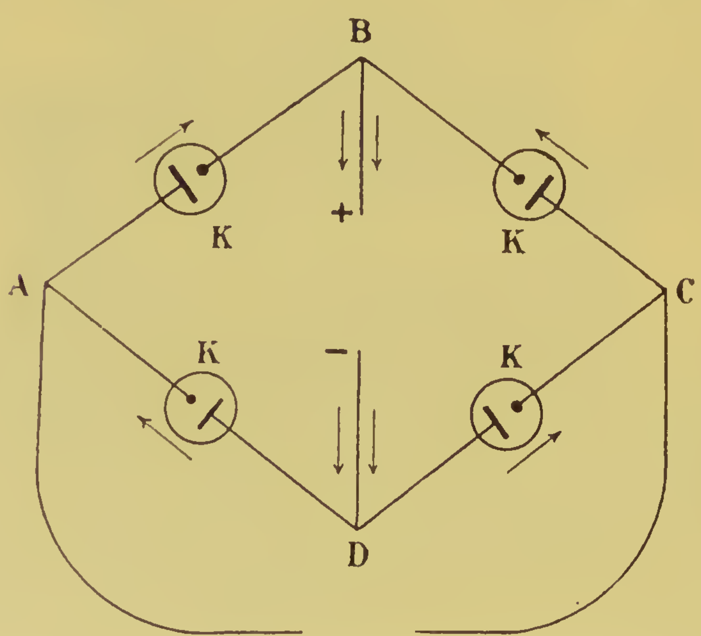


FIG. 78.—Arrangement of aluminium cells in Nodon valve.

resistance like that shown in § 93, the alternating mains can be used to charge an accumulator, if the aluminium cell is so connected up that the direction of flow from lead to aluminium is towards the positive terminal of the accumulator, and a direct current ammeter in the circuit will give readings of the mean charging current.

As half the impulses are arrested by the cell, the readings will be half of those for which the candle power of the lamp is rated (§ 88), thus, with a 32 candle-power lamp on 100 volt mains the accumulator will be charged at the rate of about half an ampère, allowing ·1 of an ampère for loss in the system. By using a

combination of cells, both phases of the current can be utilised in one circuit.

The disposition of cells shown in fig. 78 is due to Graetz, and is an application of the principle of the Wheatstone's bridge (§ 51). Four cells are taken and arranged in a circuit, as shown at K, the direction from lead to aluminium is indicated by the arrows. The alternating current is applied at A and C. No current can pass in either direction, for it is opposed by one or other of the aluminium cells, but if B and D be connected a current will flow from B to D. When A is the positive pole, the flow will be by A B, D C, and when the sign of the E.M.F. changes, and B is positive, it will flow by C B, D A, always, therefore, from B to D through any circuit joining B and D. The system may be regarded as a Wheatstone's bridge circuit, in which the resistances automatically change with the changes of sign of the

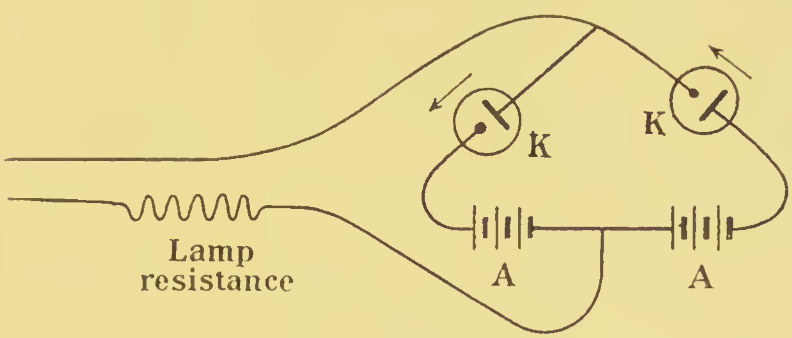


FIG. 79.—Accumulator charging with two aluminium cells.

alternating E.M.F. applied at A and C. The Nodon valve and Pollak's rectifier are arrangements of aluminium cells on this principle, and they answer quite well, not only for charging, but also for driving direct current motors, as for example, motor interruptors for coils, and for working the coils themselves. The current given out by these forms of rectifier is not smooth, but for most practical applications it answers almost as well as if it were.

Fig. 79 shows a simple arrangement by which two cells can be used instead of four, for charging accumulators. K K, as before, are the aluminium cells, they are oppositely arranged on two branches of one of the conductors of an alternating circuit, the other conductor is joined through a resistance to the middle point of a set of accumulator cells. It will be seen from the

diagram that the impulses of current will pass alternately into one or other of the accumulator sets, and will charge each in turn. By this arrangement, the aluminium cells are not called upon to resist the full back electromotive force of the impulses in the wrong direction, for one or other of them is always open to the easy passage of current. Thus the wear and tear of aluminium is reduced, and the heating of the cells is also lessened. This is useful, because the efficiency of the valve begins to fall off when the temperature rises above 70° F.

A large number of solutions have been proposed for the electrolyte. The choice among these will be partly governed by the nature of the metal used for the other pole of the cell, for it is desirable that this should not be attacked through electrolytic action. Among the chemicals which have been suggested are alkaline sulphates, especially ammonium sulphate, ammonium phosphate, potassium or ammonium chromate, double tartrate of potassium and sodium (Rochelle salt), and many others. Pollak has recommended solutions of caustic alkalies, and the compound used in the commercial form of his rectifier, though assumed to be a secret compound, is probably of this nature.

In the Nodon valve the solution is one of ammonium phosphate, which acts very well, and the aluminium poles are said to be alloyed with zinc. It is doubtful whether this addition is valuable. In its original form the Nodon valve was made of four iron cylinders, supported side by side in a wooden frame. The aluminium was in the form of short thick rods, inserted from beneath through rubber corks, and the wire connections were also below. It is now changed into a group of four cells with lead plates instead of iron, and the aluminium rods also have a different shape and are put in from above. When the cell has been in action for a time, the ammonium phosphate solution gives off ammonia, and becomes acid. Some aluminium phosphate is formed, and a crystalline precipitate gradually incrusts the interior of the cell. If the electrolyte is kept alkaline, by frequent small additions of weak solution of ammonia to take the place of the water lost by evaporation, this incrustation will be much diminished, and instead there will be merely a slow precipitation of alumina as an amorphous sediment. Chlorides are unfavourable to the valve effect, and distilled water must be used in preparing the electrolyte. If this cannot be had, tap

water may be used, after freeing it from chlorides by adding a few drops of nitrate of silver solution, the deposit of silver chloride can be separated by decantation, and any trace of silver present in excess will settle down as phosphate, and be eliminated during the subsequent preparation of the ammonium phosphate solution.

Whatever salt be chosen for the electrolyte, it must be used in strong solution to obtain the maximum conductivity of the electrolyte, and to reduce ohmic resistance and consequent C_2R losses (§ 29). This, however, does not apply in the case of solutions of caustic alkalies, for these attack aluminium if concentrated. A little ammonia, to give the liquid an alkaline reaction, may be used with advantage in any of the solutions of neutral salts used for electrolytes. The iron plates in the old form of Nodon valve remain unattacked, if the cell is properly managed, and acquire a firm coating of black magnetic oxide of iron.*

102. **A.C. Applications to patients.**—A rotary converter (§ 100) might be used for the application of "galvanic" currents to patients from A.C. mains, but it is not likely that it would often be used for that purpose. Rectified currents are not smooth enough to use. It would be possible to use a battery of small accumulator cells and to charge them through an aluminium cell occasionally as required, but better still is to have recourse to an ordinary portable battery (§ 72), because after all an apparatus of that kind is indispensable for electro-therapeutic purposes, on account of its portability. For the same reasons a simple induction coil driven by a dry cell will be preferred for "faradic" currents.

For sinusoidal currents the A.C. mains provide exactly what is required, and only need regulation by a suitable transformer. In spite of variations of contour in the curves of commercial A.C. currents, they are near enough to sine curves to be satisfactory for medical purposes.

103. **A.C. The working of large coils.**—The rectifier of Siemens (fig. 77) enables large coils to be driven with ease from the A.C. mains. The aluminium rectifier can also be used as already mentioned, finally the same appliance can be used to

* The Nodon valve rectifier is sold by Isenthal and Co., 85 Mortimer Street, W. The Pollak valve by Watson and Sons, 313 High Holborn. A simple and cheap aluminium valve apparatus for charging accumulators is made by Mr. Livett, 58 Balham Hill, S.W.

charge accumulators, and these can then be employed for the coils as already dealt with in §§ 68-71.

With a little management the Wehnelt interruptor can be made to work as a rectifying interruptor on A.C. mains (see § 71).

A form of turbine break actuated by a synchronous alternating motor has also been designed for use with the A.C. mains. It is fitted with a wheel by which it is speeded up to synchronism by hand.

High pressure transformers have also been employed to take the place of Rhumkorff coils for exciting X ray tubes. Villard proposes to suppress those impulses which are in the wrong direction by an ingenious device of a valve in the form of a vacuum tube with one pole (kathode) in a wide part of the tube

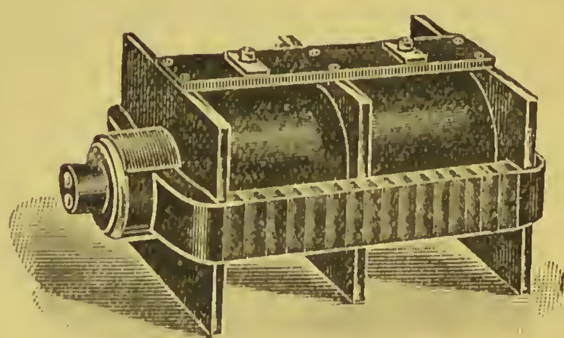


FIG. 80.—High potential transformer.

and the other pole (anode) in a narrow part. Another inventor gets rid of the opposing impulses by a synchronous motor which makes contact only at the proper moments.

104. **A.C. Small lamps and cauteries.**—For the operation of these see § 99.

105. **A.C. Motors.**—Alternating motors are now made by several firms, and apart from the question of starting they are excellent machines. For the most part they belong to the class of "induction motors," and have no commutators and brushes, consequently they need less attention than D.C. motors.

Their weak point is that they cannot well start on a load, and some arrangement with a loose pulley is generally necessary to enable the motor to be run up to speed on no load. When running steadily the load can be slipped on. Every year improvements are being made in this respect, and an A.C. motor to

start on a load will soon be attainable. Speed regulation is another weak point of A.C. motors which is in process of improvement.

106. **A.C. Arc lamps.**—The arc lamp with iron electrodes which has been recommended in the treatment of lupus will not work on an alternating current, but will work from the current of an aluminium rectifier with four cells.

The best iron lamp is the condenser lamp with iron electrodes worked from a coil or from a high potential transformer, either oil-immersed or dry. The apparatus is supplied with the lamp by Mr. Miller. This lamp and others employed for medical purposes will be referred to again in a later chapter.

107. **A.C. Polyphase currents.**—A few words on the subject of three-phase currents may be useful, because it is possible that their employment for medical purposes may become extended in the future.

A simple alternating current has been described in § 55, and its properties are fairly familiar to those medical men who are at all interested in electrical matters.

It may be spoken of as a single-phase current to distinguish it from two-phase and three-phase currents. Polyphase currents have certain advantages for industrial purposes and have recently been proposed for medical uses. In this country Dr. George Herschell* has recently written on the subject, and has described his method of generating and regulating three phase-currents for medical uses.

Figure 81 shows an apparatus designed by him which consists of a D.C. motor with three slip rings on its axle, very much as in fig. 68. The three-phase current is carried by three conductors to the primaries of three transformers coupled together for the simultaneous regulation of the currents in the three circuits.

A dynamo for generating three-phase currents is designed with three separate sets of windings in the armature, these separate sets of windings being so spaced out as to come into inductive operation in regular succession, there will then be three separate circuits of equal voltage which may be collected by brushes rubbing on six slip rings, or they may be connected up by grouping in the case of three-phase by having one end of each led to a common junction, and the three other ends led to three slip rings and so to three live wires.

* "Polyphase Currents in Electrotherapy," London, Glaisher, 1903.

Fig. 82 is a diagram to represent the nature of a three-phase current as compared with simple alternating current. A, C, B mark the tops of a wave of each of the three phases, the numbers indicate degrees of angular distance to express the

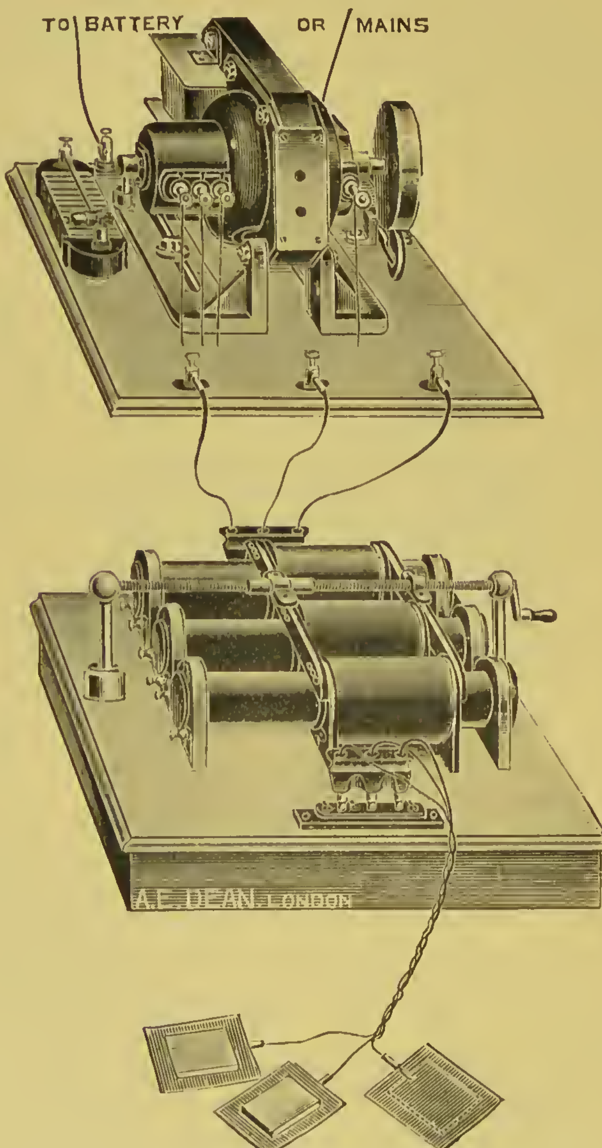


FIG. 81.—Three-phase apparatus of Dr. Herschell.

intervals in the course of a revolution of the generator at which each coil comes into operation.

The diagram, though commonly used to represent three-phase currents, must not be thought to imply that all the changes

indicated take place in one conductor, indeed for some purposes it would be better to represent three-phase currents by three simple sine curves on three separate horizontal lines, connected by vertical lines to indicate the time-relationships of the rise and fall of E.M.F. in each conductor. If one imagines this to be done with the diagram, it would be seen that whenever one of the circuits is occupied by a positive wave crest, the other two are negative to it.

A three-phase transformer for medical use has three iron cores wound with equal turns of wire for the primary coils, and three secondary windings, also of equal numbers of turns; the three ends of the primary windings are joined together, and the commencements of the three secondaries are also joined together, their other ends being led out to three binding screws, from which they pass to the patient by three wires ending in three electrodes. Three-phase currents of low periodicity have been

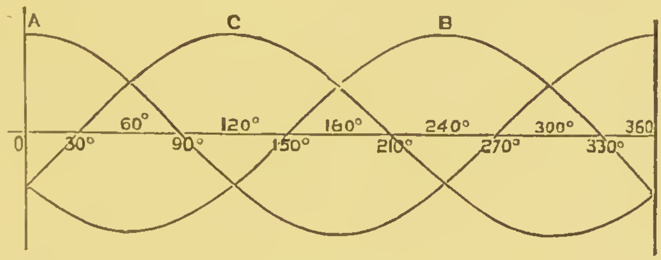


FIG. 82.—Diagram of three-phase currents.

found specially useful in the treatment of some abdominal disorders, and are also recommended by Dr. Herschell for use in the electric bath (Chap. VIII.).

108. **Dangers of electric lighting mains.**—In all applications of current from the mains to patients it is necessary to take proper precautions to prevent accidents. These may arise from defects in the design of the apparatus, either inherent, or as a result of wear and tear, from loose connections, &c. Care must always be taken to avoid the risk of discharges to earth through a patient, as it is quite possible to employ resistances in such a way as to prevent dangerous discharges from pole to pole through a patient, and yet to have things so arranged that the patient might receive a dangerous discharge from one pole of the apparatus to earth. For instance, if all the safety resistance should be on one side of the patient, say on the negative side,

and there were none on the positive side, an accidental contact of the patient with a good earth, as through a gas or water pipe, or a damp wall or floor, might expose him to the full pressure of the mains.

On circuits of 100 volts this is bad enough, but when the differences of potential possible in a lighting company's network are 200, or 250 volts, or even more, it becomes obvious that the danger is not an imaginary one. Take for instance the arrangement in fig. 62, where the patient is in a shunt circuit, having no resistance on one side of him except the lamp B. It is not quite safe. A much better plan would be to lead the current to the patient from points near the centre of the wire resistance by means of two travellers, which could be moved towards each other, or away from each other, to give the necessary slope of potential, or else to have two such resistance coils in series, with one traveller on each, and stops to limit their ranges towards the ends of the resistances.

Another matter to be attended to in shunt circuit regulation, is the maintenance of the continuity of the resistance wire. If it should break from any cause, or become disconnected at one extremity, the patient might receive the full pressure of the mains, if his circuit bridged the interval of the gap. In general, the lamp resistance provided on the shunt circuits acts as a safety indicator. If it should not light up as usual, or if it should light up too brightly, it must be taken as a warning that something needs attention.

With electric baths, where the patient is largely deprived of the protection generally afforded him by the resistance of his skin and clothing, special attention must be given to the dangers of shock to earth. Quite apart from the matter of electric baths, it may be laid down as an axiom that no metal connected in any way to an electric light fitting, should be in reach of any person in a fixed bath of any kind. Electric light switch covers may be alive, from accident or bad workmanship, and if so a person standing in a bath, with pipes and taps of metal attached to it, might easily be killed by touching one.

The accidents at the Fulham baths at the end of 1902 occurred in this way. Two men standing in water, or on a wet bath room floor, touched an iron pipe, which happened to be alive through defective wiring arrangements for the lighting of the building, and both were killed by a pressure of 200 volts.

It is childish to attempt to insulate a bath if it is fitted with a waste pipe and metal water pipes. It must be regarded as permanently earthed, and protected efficiently from that point of view, if it is to be a safe appliance.

CHAPTER VI.

ELECTRICITY OF HIGH POTENTIAL. STATICAL ELECTRICITY.

Historical. Description of instruments. The Holtz machine. Wimshurst's machine. Conductors and electrodes. Treatment by charging. The static breeze. Treatment by sparks. The Leyden jar. Morton's method. Effects of static electricity.

109. **Electrostatic methods.**—In comparing the so-called statical methods with other kinds of electrical treatment, it is found that an important feature of the former is, that very high electrical potentials, even up to a hundred thousand volts or more, are employed.

These enormous voltages can usually be applied to patients without danger, because of the small capacity (§ 17) of the machines commonly employed for producing them. The actual current in the discharge from an electrical machine is very small. Any rise in the capacity of the apparatus is accompanied by an increase in the magnitude of the discharge, and in the sensation of shock, thus machines with large prime conductors, or those which have their capacity greatly augmented by Leyden jars (§ 19), may give shocks which are severe or even dangerous.

The first form of electrical machine was a large sulphur ball which was excited by one hand as it was revolved by the other. It was made by Otto von Guericke of Magdeburg in 1672. Some interesting reproductions of old figures of early electrical machines are given by Dr. Mount Bleyer, of New York, in Bigelow's "System of Electro-Therapeutics." Subsequently resin was used, and then a glass cylinder, instead of the sulphur ball. In 1740 Winckler excited the glass by means of horsehair cushions covered with silk instead of the hands.

In 1760, Ramsden substituted a circular glass plate for the cylinder, and his apparatus was, until recently, in common use.

In modern machines induction is utilised for producing the electrical separation, and on this account they are often known as influence or induction machines. In 1865, Holtz of Berlin invented a machine which, when charged from an electro-

phorus, would continue to produce electrical separation by induction. It proved to be far superior to the older frictional machines, and quickly supplanted them in spite of certain drawbacks. In its original form, the cutting of its plates presented difficulties, it required to be excited from an outside source before it could begin to work, it was liable to lose its excitation if worked upon open circuit, and it had a tendency to reverse its polarity during action. From its good qualities it has been made the object of much work in the hope of remedying its defects, and it has been brought to a high degree of perfection by the instrument makers of the United States, where the Holtz machine is in almost universal use for electro-therapeutics.

110. **The Holtz machine.**—In its simplest form it consists

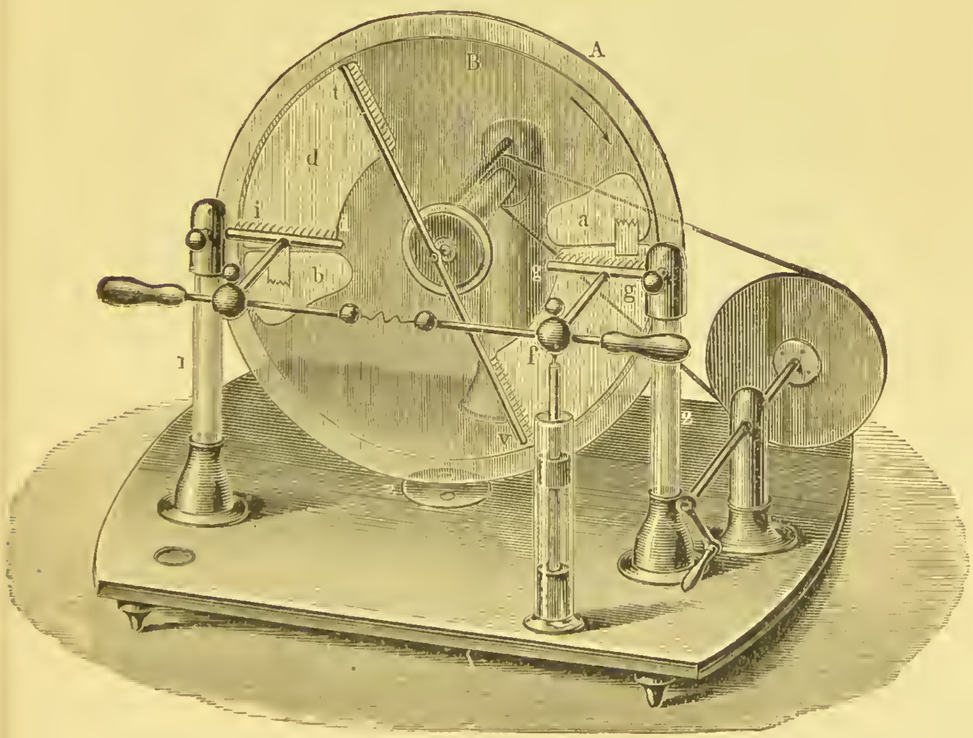


FIG. 83.—Holtz machine.

of two plates of glass, A, B, one having a diameter slightly greater than the other. The larger plate is fixed, but the smaller one rotates. The plates are close together but do not touch. In the fixed plate are two openings or "windows," *a*, *b*, diametrically opposite to each other. Two pieces of paper called "field plates" are glued on to the fixed plate, one above

the window on the left side, and one below the window on the right. They are on the surface of the plate away from the revolving one. A tongue from each of these pieces of paper protrudes through each aperture, and nearly touches the revolving plate. The plate is rotated in an opposite direction to that in which the tongues point. Two metallic combs, *g*, *i*, supported

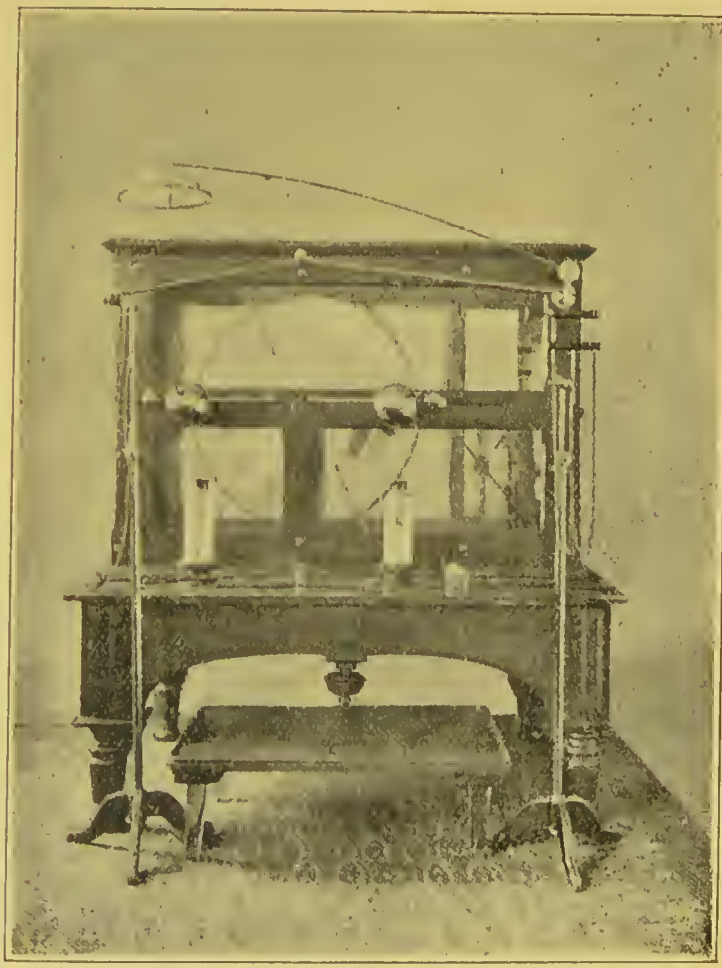


FIG. 84.—The American Holtz machine, medical type. (Waite and Bartlett Manf. Co., New York).

by brass rods with knobs, *j*, and mounted on glass supports, form the prime conductor. Two smaller brass rods, with ebonite handles, and knobs act as discharging electrodes, by means of which the length of spark can be regulated. The rod *t v* is called the neutralising rod, and is said to make the machine less

likely to reverse its polarity when working. Before starting the machine, one of the field plates must be charged from an outside source, and the knobs of the discharging rods are to be brought together. The moveable plate is then rotated rapidly, and a series of sparks will pass between the electrodes.

In the modern machines used in electro-therapeutics there are many modifications in details. First the machine has four, six, or eight pairs of plates, and is enclosed in an air-tight case. The fixed plates instead of being round, with windows and a hole for the axle, are oblong, are held in place by grooves in the framework of the case, and each is made in two pieces which do not quite touch each other, and so leave room for the axle to revolve between them. The "field plates" of paper are glued to the fixed plates on the side which faces the rotating plate or near side, instead of being on the opposite or far side. This prevents the reversals of polarity during action, which occurred with the original Holtz machine, by preventing the formation of an accumulated charge of opposite sign on the near side of the fixed plate, as used to be the case when the field plate was attached on the far side.

Machines for electro-therapeutics usually have revolving plates thirty inches in diameter, and are generally driven by an electric motor. For providing the initial charge which is required to excite the action of the machine, a small Wimshurst or Voss machine is fitted in the corner of the case of the instrument.

111. **The Voss or Toepler Machine** is also used directly as a medical static machine. It is more nearly a self exciting machine than the Holtz, but like that form, it is less sure in its action than the Wimshurst machine.

The Voss machine resembles the Holtz in a general way, but the moving plates carry a few sectors and these in their rotation touch a pair of brushes which are carried by two bent arms which connect with the field plates and so convey charges from the moving plate to the armature of the fixed field plates.

The Wagener mica plate machine is a modified Voss machine in which the moving plates are made of pieces of mica cemented and compressed together with shellac. They are light and can be safely driven at a very high speed. This type of static machine can be seen in London*.

112. **The Wimshurst machine.**—The Wimshurst machine

* Messrs. Smith and Wade, 20 Baker Street, W.

has the advantage over the Holtz that it is self exciting, and its polarity will not reverse under ordinary circumstances while it is in action. It consists of two circular glass discs (or any even number up to twelve), mounted in pairs upon a fixed horizontal spindle in such a way that they rotate in opposite directions at a distance apart of not more than a fraction of an inch. Each disc is attached to the end of a hollow boss of wood, or of metal, upon which is turned a small pulley. The pulleys are driven by a cord or belt from larger pulleys attached to a spindle below the machine, and rotated by a winch handle or by a motor, the difference in the direction of rotation of the discs being obtained by crossing the alternate belts.

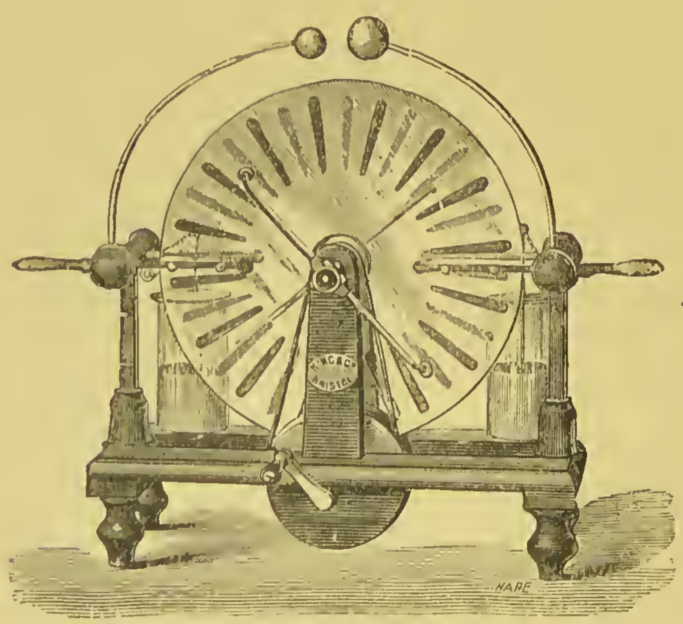


FIG. 85.—Wimshurst machine.

Both discs are well varnished, and attached to the outer surface of each there are radial sector-shaped plates of tin-foil or thin brass disposed around the discs at equal angular distances. These sectors are not essential to the action of the machine, but they make it more easily self exciting.

Twice in each revolution the two sectors situated on the same diameter of each disc are momentarily placed in metallic connection with one another by a pair of fine wire brushes attached to the ends of a curved rod, called the neutralising rod, supported at the middle of its length by one of the projecting ends of the fixed spindle upon which the discs rotate, the

sector-shaped plates just grazing the tips of the brushes as they pass them.

The position of the two pairs of brushes with respect to the fixed collecting combs and to one another is variable, as each pair is capable of being rotated on the spindle through a certain angle; and there is one position of maximum efficiency. This position in the machine appears to be when the brushes touch the discs on diameters situated about 75° from the collecting combs, and 30° from one another.

The fixed conductors consist of two forks furnished with collecting combs directed towards one another, and towards the two discs which rotate between them, the position of the two forks, which are supported on ebonite pillars, being along the horizontal diameter of the disc. To these fixed conductors are attached the terminal electrodes, whose distance apart can be varied. Leyden jars are usually fitted to the machine by the makers, but these must admit of their outer coatings being disconnected, before the machine is used for treating patients.

The machine is very efficient and perfectly self exciting, provided there are sufficient sectors, generally requiring neither friction nor any outside electrification to start it, and this is one of the most remarkable features of the apparatus, for under ordinary conditions the machine works at is full power after the second or third revolution of the handle. It has been suggested that the initial charge is obtained from the friction of the air, and that chiefly between the plates, but nothing certain is known about it.

When the glass plates are very large they are heavy and apt to crack. On this account a modification of the Wimshurst machine is made with ebonite plates. These may safely be driven at a very high speed. There is, however, a grave objection to the use of ebonite plates in expensive machines because of its tendency to deterioration through a chemical change of its surface, by which it loses its insulating properties; moreover, the plates of ebonite cannot be kept true, but bend and buckle.

Mr. Pidgeon has introduced modifications into the Wimshurst influence machine by adding fixed inductors to reinforce the action taking place between the plates, by increasing the size of the tin-foil sectors, and by very carefully insulating the sectors from leakage to each other and in this way he has succeeded in increasing, very notably, the output of a machine of a given size

as compared with the output of an unmodified machine having plates of the same dimensions.

The Wimshurst machine is at its best when the resistance of the discharging circuit is very high, and the opposite condition of a free discharge in the outside circuit suits the Holtz type of machines best.

It has been proposed to enclose the Wimshurst machine in a

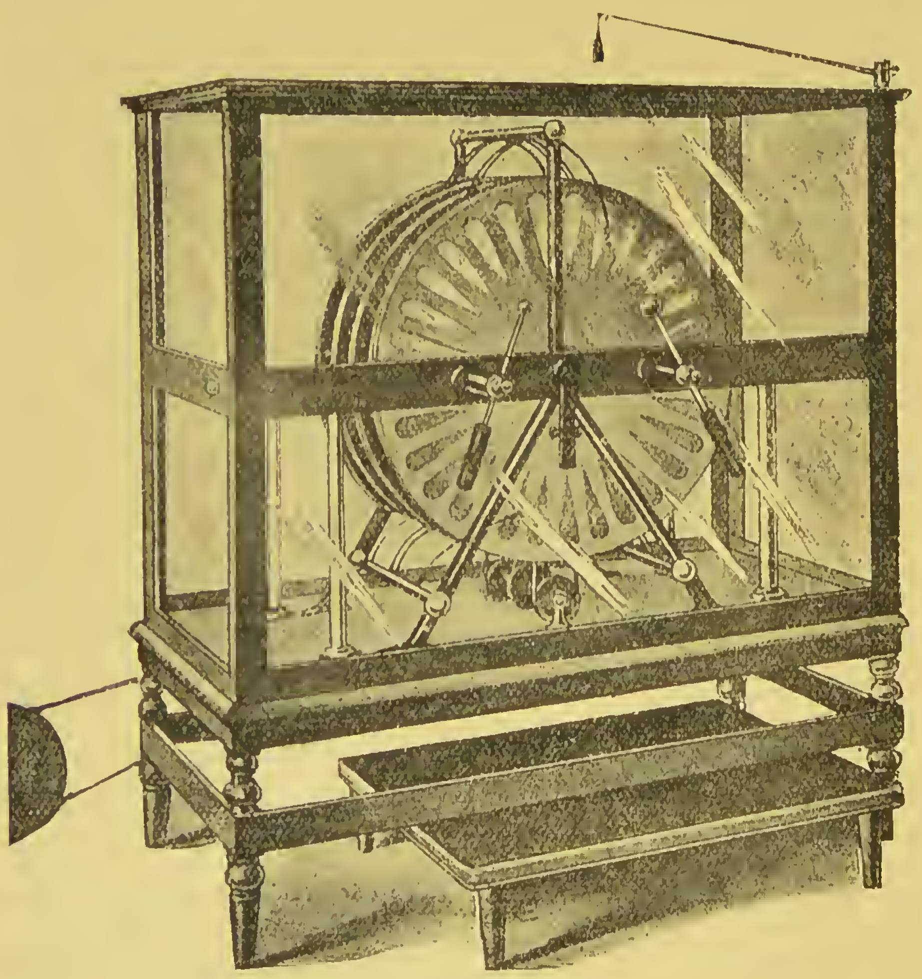


FIG. 86.—Wimshurst machine.

strong metal case and to work it under an air pressure of several atmospheres in order to reduce leakage by brushing. Hitherto this idea has not been fully realised, but it is possible that an arrangement of this kind may in time be made successfully.

M. Gaiffe, of Paris, has lately introduced a sectorless Wimshurst machine, with a simple attachment of the plates, which

makes it very easy to remove them for cleaning. He proposes by this means to do away with the need for a case and so to cheapen its cost and make it more accessible for purposes of adjustment. It is probable that the labour of keeping such a machine clean will more than counterbalance the supposed advantages of saving the cost of a case. In the smoky air of towns the electrostatic attraction of a machine in action will attract soot and defile the plates in less than half an hour.

A Wimshurst machine for therapeutic work should have eight plates of thirty or thirty-six inches diameter. The figure shows a machine built by Mr. C. L. Schwind of Broomfield, near Derby. This machine, without any Leyden jars, gives streams of sparks nine to ten inches long. It is enclosed in a roomy case to prevent waste by leakage from the machine to the case, and to protect it from damp and from dust. It runs silently and smoothly and has not failed on any occasion. It is driven by a $\frac{1}{4}$-horse electric motor.

113. **Medical applications.**—Whichever form of machine be adopted the essential requirements are the same, namely, the machine must be large enough, it must be built to stand hard work and it must be enclosed in an air-tight case; pads of indiarubber under the feet of the machine help to reduce the noise in working. The effects which large statical machines can produce are much better than those which can be obtained with small machines, and the therapeutic results of their use are obtained so easily and so promptly that it is a pleasure to use them. The progress made in statical treatment in the last few years is due almost entirely to the work done in the United States, where the Holtz machine has been much improved and is now employed very widely by medical practitioners who find a static machine valuable not only for therapeutic purposes but also for X ray work. In country places the occasional X ray work of general practice is admirably served by a static machine.

In 1898 I had the pleasure of making the acquaintance of Dr. Monell, of Brooklyn, the author of "A Manual of Statical Electricity in X Ray and Therapeutic Uses." With his assistance I procured from New York a set of electrodes and apparatus for use with the static machine and he was good enough to give me a full practical demonstration upon the modes of application which he had elaborated and was teaching

in Brooklyn. It gives me much pleasure to make grateful acknowledgment of the instructions of Dr. Monell, as communicated personally and as learnt from the pages of his book, which is indispensable to any worker with the static machine.

Dr. Monell recommends that the patient be insulated upon a platform with glass legs which is connected to one pole of the machine by a conductor; the electrodes, whether knob, or point, or roller, are connected to earth, and the second pole of the machine is also earthed. The advantage of this mode of procedure, which is rendered possible by the power of modern machines, is that the instruments handled by the operator are at zero potential, which makes it unnecessary to use any insulating device to guard against shocks. The earthing of the

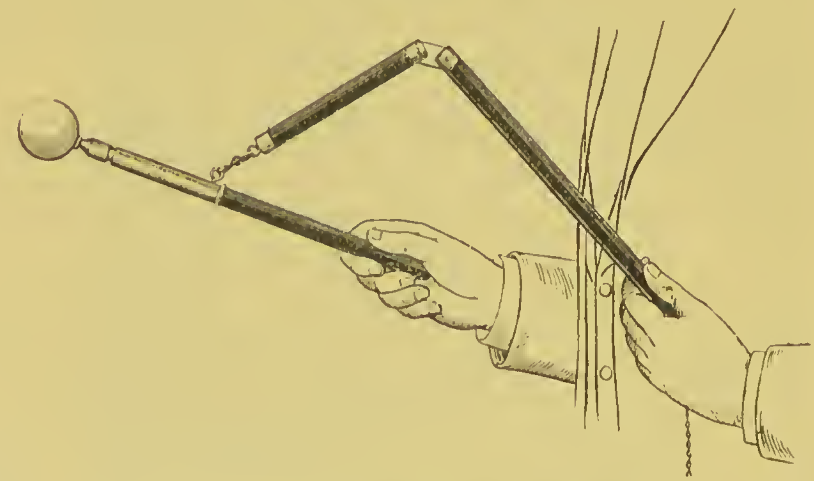


Fig. 87.—Dr. Monell's electrode holder.

electrodes is arranged by a long light chain connected at one end to a gas or water pipe in the building, and fitted at the other end with a handle shaped like a flail to which the electrodes are hung. This handle, or "electrode holder" (fig. 87), of Dr. Monell is an ingenious contrivance, and serves to support the weight of the electrodes during their application. It is held in the left hand close to the body, and supports the weight of the electrodes very much as a crane supports a weight. Thus the right hand is used to hold and direct the electrode, while the left hand supports the weight of it and so relieves the right arm.

For a means of changing the polarity of the electrodes or of the patient a solid ebonite rod with brass terminal knobs is held

in a wooden clamp between the dischargers of the machine (fig. 88). The upper knob is for the earth connection, the lower is for the connection to the platform. In this way either pole of the machine can be put to earth while the other is connected to the platform.

114. **Accessory apparatus.**—The accessories which are essential for the proper use of a static machine are as follows :—A platform with glass legs, chains for earthing conductors, a single point electrode, a multiple point electrode, a brass ball electrode, a brass roller, and a Monell's handle for holding these; also a swinging brass rod carrying a wire tassel which

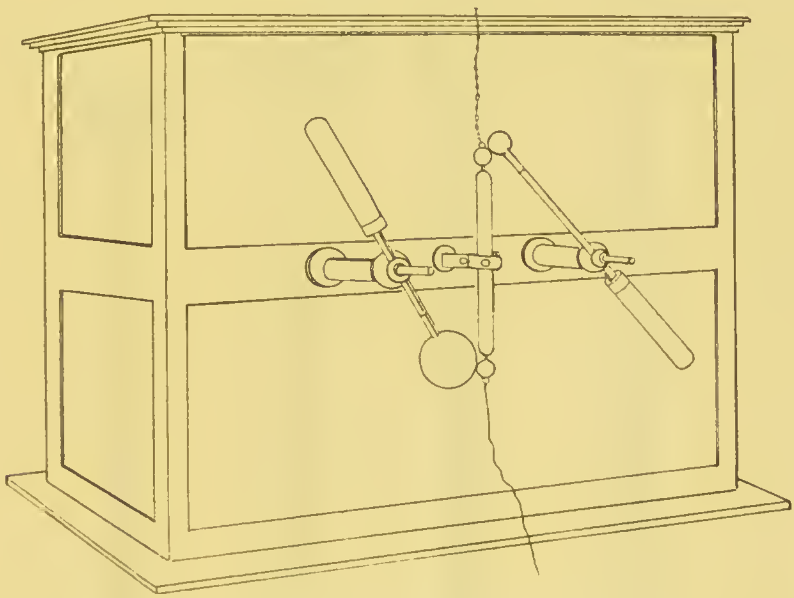


FIG. 88.—Front of case, showing ebonite rod with connections to earth above and to platform below, and arrangement of poles.

is best attached to the case of the machine as shown in fig. 86. These, with a brass adjustable stand to hold a fixed electrode, a sheet of brass for a footplate, and a connecting rod or wire to connect the platform to the machine are enough for most purposes. There are other electrodes for more special uses, and it may be of advantage to have Leyden jars arranged for use in certain cases. These are often fitted to the machine. Their applications will be considered in a later paragraph.

Hitherto the demand in Great Britain for static machines adapted to medical purposes has been a small one.

Messrs. Watson and Sons, of High Holborn, have taken up

the manufacture of the type of machine shown in fig. 86, and are prepared to supply an outfit with all accessories complete.

115. **The insulated platform.**—This should be strongly made and well designed. A bad platform may reduce the efficiency of the treatment by one-half, through losses of charge from leakage. To reduce these losses as far as possible the platform must be made with all corners and edges carefully rounded off and made smooth, the glass legs should be at least ten inches long, and twelve inches is even better. There should be a rounded beading or edging to the platform, to prevent the

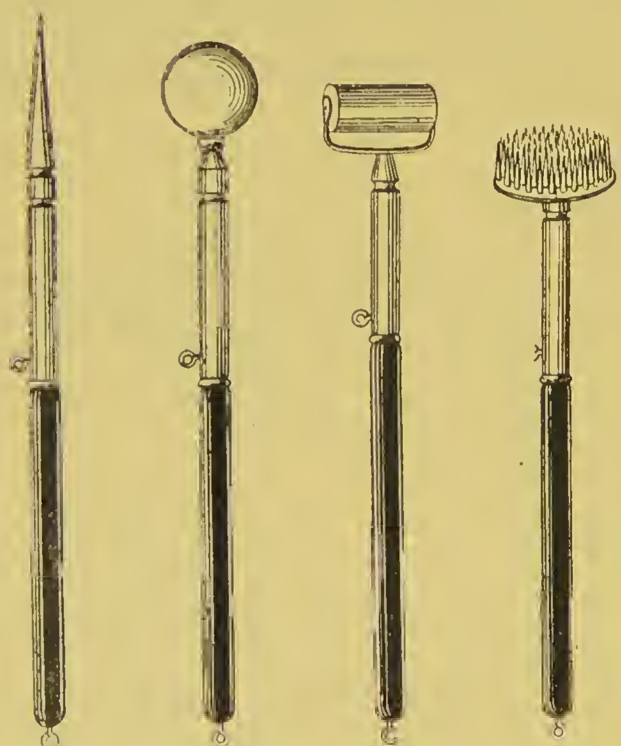


Fig. 89.—Electrodes.

chair or stool from slipping off through any movements of the patient. The dimensions recommended by Monell are forty-two inches by twenty-seven. The platform and the glass legs must be strong enough to support the weight of the heaviest patient. Owing to the size of the platform it is useful that the case of the machine shall be so built as to permit of the platform being pushed underneath it when not in use, otherwise the platform takes up a great deal of floor space.

116. **Electrodes.**—Fig. 89 shows the four chief electrodes,

namely, the single point, the multiple point, the knob or ball electrode, and the roller. The eye at the side of the electrodes is for attachment to the Monell handle, while the eye at the

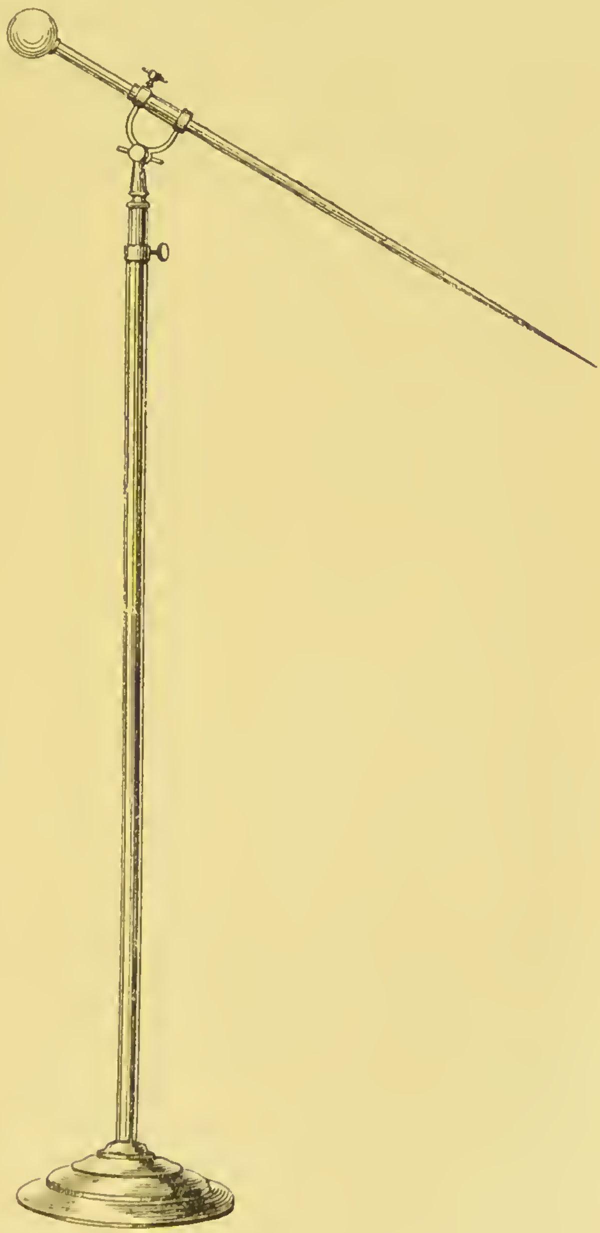


FIG. 90.—Stand electrode.

end is for hanging up the electrodes upon hooks when they are not in use. Fig. 90 shows a stand with combined ball and point electrode; it is useful in certain applications, the stand is hinged

at the top, and can be raised and lowered to bring either the knob or the point into any desired position.

The single point electrode is used for giving the static breeze, and the multiple point is for the same purpose, its effect being rather stronger. Bordier recommends a blunt point with an angle of 90° as most effective for the effluve. The ball electrode is three inches in diameter and is used for administering sparks. The roller also gives spark discharges, but in a special way. It is used by rolling it over the surface (clothed) of the patient. When this is done, showers of very short sparks are given off, of a length equal to the thickness of the layer of clothing between the roller and the skin. These short sparks produce a very strong sensory effect, and the roller electrode must therefore be used only with very rapid movements, otherwise the sensation becomes unbearable. It is a valuable electrode in certain conditions, and its effects are highly stimulating.

117. **Distinction of poles.**—To test the polarity of the machine. Take the earthed point electrode in the hand, and present it to a knob of the machine in action. Gradually bringing it nearer and nearer, as it approaches the positive knob a star of light will appear on the point, even at a distance of several inches, and this star of light will remain without much alteration until the point is brought up almost into contact with the knob, then small sparks pass. If approached to the negative pole in the same way, the discharge takes the form of a visible brush or spark, when the point is still at a distance of two or three inches from the knob. It is easy to recognise these differences in the discharge to the point, and from them to know which pole is positive and which the negative.

118. **Simple charging.**—The patient is to be seated on a stool or chair on the insulated platform, and the brass plate connected with the machine by a wire or chain, or brass crook. On the brass plate is placed a footstool, and on that the patient rests his feet. The machine is then set in action and its polarity tested. Then bring the positive pole into contact with the conductor to the platform, and take the other one to the earth connection and start the machine. The patient is then charged positively. The presence of nails in the seat of the stool is undesirable.

As soon as the patient becomes charged he feels certain sensations. The hair begins to move, and on the scalp and face, and

to a less degree on other parts, he feels as if lightly touched by gossamer or cobwebs. If any piece of furniture or other object or person be near, he may feel a breeze blowing towards him from it. If the platform is too near the machine this breeze will be particularly felt from the direction of the grounded pole of the machine. The platform, therefore, should be two feet or more away from the side of the machine and from any furniture or the walls of the room, and the friends of the patient must be warned not to touch or hand anything to the patient, otherwise a spark will pass between them, and both will receive a shock.

Simple charging (positive or negative) may be continued for fifteen minutes or longer. Its effects are agreeable and tonic. It is the mildest form of statical treatment and is usually given in combination with a brush discharge to the head or spine or both, it is also a necessary part of all statical treatment administered to a patient on the insulated platform. Usually the patient is charged positively because that is the natural condition of charge of a patient in the open air or on a mountain side. It has been said that the negative charge produces feelings of prostration while the positive produces invigoration. This is probably incorrect, at least it is not supported by everyday experience, though the idea serves to decide that when simple charging is desired the positive charge shall be preferred.

119. **Charge and discharge.**—In addition to the continuous electrification described in the last paragraph, there is a method of alternately charging and discharging the patient which is described by Dr. Monell, and recommended by him as a more energetic tonic treatment than the simple charging. He has given it the name of "Potential Alternation," and it is performed as follows:—While the patient is being charged, the knob or ball electrode, grounded as usual, is brought near to the knob of the machine from which the patient is being charged. As it approaches, a sharp cracking spark passes and the patient is discharged, to be immediately charged again from the machine and again discharged in the same way as before. The chargings and dischargings follow each other with a rapidity which depends upon the activity of the machine and the width of the gap across which the spark must leap. The patient's hair can be seen to oscillate in time with the sparks, especially if the head breeze electrode be in position during the application. This method has the disadvantage that the stream

of sparks makes a distracting noise which some patients cannot endure. Other patients do not mind the noise so much and find the application not unpleasant.

120. **The brush discharge or breeze.**—If when the patient is charged on the platform a grounded point electrode is presented to him, he feels the sensation of a wind blowing towards him from the point; this is the electric breeze, or wind, or *souffle électrique*. It can be felt when the point is a yard away, but becomes much more strongly felt when the point is brought nearer, right up to the distance at which the discharge changes from the silent discharge to that of sparks. The safe distance varies according to the polarity of the patient. When he is positive the grounded point can be brought much closer without sparking than when he is negative. The breeze which is felt as a cool wind upon the bare skin acquires a pricking hot character when directed upon covered parts, and the prickly sensation is greater when the patient is positively charged. Usually, therefore, the patient is charged positively, except when the mildest form of breeze is desired, as may be the case with timid or unaccustomed patients. The breeze produces a very grateful sensation when applied to the scalp, and to the nape of the neck, and it is usual to arrange a special electrode for this head breeze by means of a hinged arm supporting a wire tuft or tassel, or a crown shaped metallic arrangement. In figure 86 this is shown as a rod projecting out from one top corner of the case, it has an universal joint enabling it to be swung out or in and raised or lowered to bring it into place over the patient's head as he sits upon the platform. The scalp can also be "breezed" by the point electrode held in the operator's hand.

The breeze is called the "negative breeze" when the patient is positive and *vice versâ*. The breeze can be varied in strength by varying the distance between the point and the patient's surface. When the strongest effects are desired, the point (single or multiple) is brought as close as is possible without sparking, the effect then is something like a douche of hot water, and may be so strong as to be unpleasant, especially if kept acting for long upon one spot. It is more easily borne if the electrode is kept moving over the surface. The effect of a strong negative breeze upon the spinal region and the back is very invigorating, and it leaves a warm glow or after effect. As the effect of clothing in modifying the sensations of the breeze

discharge is so marked it is occasionally useful to vary the thickness of clothing to suit the requirements of the case, and this can best be done by using a woollen shawl, which may be thrown over the patient at any part where the strongest stimulation is desired. All the fabrics used for clothing do not behave alike in modifying the sensations produced by the breeze, for occasionally the corsets (or the back of the waistcoat in the case of male patients) may prevent the breeze from penetrating satisfactorily. It is not often, however, that difficulties arise, and when they do it is generally possible to overcome them. Occasionally the metal parts of the stays, or buckles, or hair-pins, or fine gold chains worn round the neck, or a steel key chain in the side pocket will cause some pricking or discomfort at the wrong place, and must be attended to.

When the patient's skin and underclothing is very moist from perspiration the effect of the breeze is greatly diminished, and patients must be told not to walk hurriedly to keep their appointments in warm weather ; occasionally in very close summer weather the roller must be used instead of the point.

The breeze may be modified and strengthened by interrupting the charge as it passes from the machine to the patient ; this is easily done by moving the conductor of the machine a little distance from the knob which leads the current to the platform.

The effect of the breeze is to produce profound cutaneous sensory impressions which can be adjusted so as to be either soothing or highly stimulating. In many cases of neuralgic pain, including headache, the effect is quite magical, that is to say, the breeze skilfully directed upon the affected region for five or ten minutes will remove the pain entirely. In addition to this local effect, which is often very valuable, there is a general invigorating effect from the breeze applied to the head, the nape, and the spine, for which patients are very grateful. The sensations may be compared to the effect of those douches used in hydropathic establishments, with the great advantage that they can be given to the patient without any removal of clothing.

121. **Treatment by sparks.**—For giving sparks the knob electrode is used, and as the sensation of a spark is disagreeable they must be given in as skilful a way as possible to avoid all unnecessary discomfort to the patient. The important point is to give only one spark at a time and not a volley. To do this

the knob, earthed as usual, is swept quickly in a curve past the place at which the spark is aimed so that it is away again and out of range before a second one can follow the first. With a little practice this becomes easy. The sparks may be repeated as often as it is judged to be necessary. Long sparks must not be directed upon bony prominences, nor upon any place where the bone is thinly covered with soft tissues, and great care must be taken to prevent any spark, accidental or other, to the face, to the female breast or to the testicles. The length of the spark can be decreased by partially discharging the patient before giving the spark, and this is easily done by the operator placing his foot upon the edge of the platform, and so causing it to leak away part of its charge. Sparks from a knob are more severe than those from the point or roller ; the sensation produced by a single well directed spark is just that of a blow, the sensation of a blow or shock depending mainly upon the sudden forcible muscular contraction caused by the spark. It is as well to give the patient notice just before each spark. With ladies the sparks must usually be weakened in the manner indicated.

122. **The roller: electric frictions.**—When the roller is rolled over a clothed surface, showers of short stinging sparks pass off from it to the patient, and the thicker the layer of clothing under the roller the sharper are the sensations. Thus they can be made stronger by a woollen shawl thrown over the clothing, and milder by the removal of an outer garment. The sensation is severe and leaves a tingling glow behind it which persists for some time. To use the roller it is best first to discharge the patient by means of the foot on the platform, and then quickly to put the roller in place, withdrawing the foot and sweeping the electrode over the surface immediately. All should be done in a few seconds, or the patient may protest. As in the case of long sparks, patients like to receive notice of the roller, if it is to be applied to any part of the back where they cannot see it coming.

123. **The Leyden jar.**—This apparatus (see § 19) was discovered in 1749. Owing to the arrangement of its coatings it has a large capacity, and in its discharge there is a larger "current" than in the spark from the prime conductor of a machine as ordinarily constructed.

This makes itself felt as a more severe shock when the discharge takes place through any portion of the body. The

Leyden jar is therefore used when it is desired that the patient shall receive a painful shock.

In former days the comparative feebleness of the machines in use made it necessary at times to use Leyden jars to secure the strong effects, which can now be produced more agreeably by the ordinary spark discharge from a knob electrode. They were used by first charging them from a machine, and then bringing them to the patient and discharging them through him by means of conductors. They were also used in connection with an apparatus known as Lane's discharger, with ordinary cords and electrodes, like those described in the last chapter, and in a book on "Electricity and Medical Electricity" written by Adams in 1791, the frontispiece illustrates a physician of the period electrifying the muscles of a child's forearm in this manner.

This mode of treatment, however, seems to have been completely forgotten, for it is not mentioned in later writings so far as I am aware. In recent years a much better method of using Leyden jars has been devised and brought to perfection by Dr. W. J. Morton of New York, and, as worked out by him, it has now become an important method of treatment, which has met with universal acceptation. In a report presented to the American Electro-Therapeutic Association in 1900, the early methods of using Leyden jar discharges in this way are fully described, with diagrams; the method of Dr. Morton (see next section) is compared with the ancient methods, and its utility and originality is upheld.

124. **Dr. Morton's method.**—In the illustration of the Wimshurst machine (fig. 85), two Leyden jars are shown with their inner coatings connected to the prime conductors, one to each; the outer coatings are also connected by a wire, which can be removed at will. When the outer coatings are disconnected, or the jars are removed entirely, the machine in action produces a stream of thin purplish sparks, and if the finger be placed between the discharging electrodes, the sensations, though unpleasant, are of the nature of a slight pricking rather than of a shock. If the jars are now connected to their respective electrodes, and their outer coatings are joined by the wire, the sparks between the electrodes alter their character, becoming less numerous, much brighter, much longer, and much more noisy. They also produce severe shocks if the fingers are

placed in their path. As the distance between the knobs of the discharging electrodes is increased, the sparks become louder, more vivid, and less frequent, until the air gap is too great for the discharge to cross. The Leyden jars are fitted to the machines to make their discharges more powerful. If the wire joining the outer coatings of the jars be interrupted by a short air gap, sparks will leap across it simultaneously with those passing between the electrodes.

Many machines are fitted with a pair of binding screws in the circuit, joining the outer coatings of the Leyden jars. This makes it easy to connect or disconnect this part of the circuit. When a wire is used to bridge over the interval between the binding screws, the outer coatings are connected, when it is

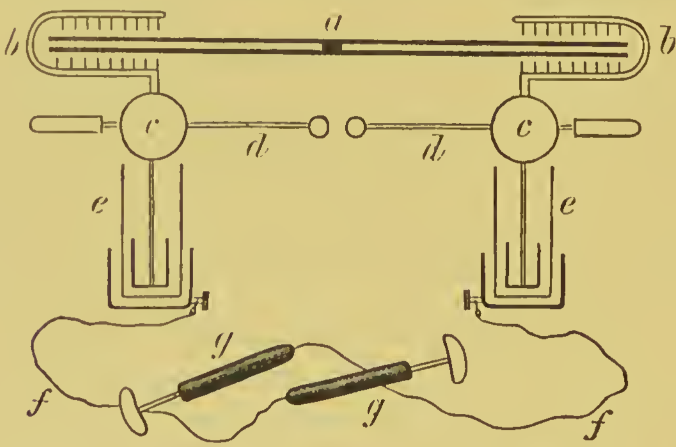


Fig. 91.—Plan of Dr. Morton's method. *a.* Plate of machine. *b.* Collecting combs. *c.* Prime conductors, with discharging rods, *d.* *e.* Leyden jars *f. g.* Wires and electrodes attached to their outer coatings.

removed they are disconnected. Dr. Morton of New York has advocated the use of this portion of the circuit between the outer coatings for purposes of treatment. With a pair of ordinary conducting cords and electrodes (fig. 91) attached to the binding screws mentioned above, Leyden jar shocks can be administered to a patient, and their severity can be controlled by adjusting the distance between the discharging knobs of the prime conductors. When the machine is in action, a shock is felt by the patient every time a spark passes between the discharging knobs. Dr. Morton has given this method the name of treatment by "static induction," and the utility of the method is undoubted for purposes of treatment. Further, Dr. Morton has

claimed that by the use of very small Leyden jars, and with the discharging knobs very close together, the shocks become almost painless, while still setting up vigorous contractions in the muscles, and may then be made extremely useful for purposes of testing.

It is of the utmost importance to adjust the sparking distance between the discharging electrodes on the machine before commencing the treatment; from an eighth to a quarter of an inch is generally sufficient; indeed, with quarter inch sparks, the treatment is severe; but the severity of the shock depends also upon the size of the jars, and is more severe with large jars.

Modern statical machines for medical treatment are now generally fitted with pairs of Leyden jars of several sizes for Morton's method, and have a simple switch arrangement for connecting or disconnecting the jars as required. The rate at which the shocks follow each other is determined by the speed of the machine. The effect produced is comparable to that of a slowly acting induction coil, and moistened electrodes applied to the bare skin are to be used.

By a further application of a helix of wire between the outer coatings, high frequency effects can be obtained.

The regulation of the discharges in Morton's method is effected by adjustments of the sparking distance between the knobs of the discharger, *d*, *d*. This varies the potential at which the jars can discharge. It has also been proposed to vary the capacity of the condensers, and this has been done by Marie and Cluzet by using Leyden jars of special shape in which the coatings can be brought near together, or separated more widely apart. The effect of doing this upon the capacity of the system will be evident from § 17 which deals with the influence upon the capacity of a body of an "earthed" conductor near it. The nearness of an oppositely charged body has an effect upon the capacity of a conductor, which is proportionately greater than that which is produced by an "earthed" body in its vicinity.

Truchot* has designed an ingenious contrivance for applying Morton's method when the machines are unprovided with Leyden jars. A tube of glass is taken long enough to reach horizontally across from one prime conductor of the machine to the other, and a little over, and two tin-foil armatures are glued

* *Archiv. d'élect. médicale*, 1889, p. 333.

to its outer surface at points where they touch the two prime conductors.

Inside the tube two moveable metallic cylinders slide, they act as the inner coatings and correspond to the outer armatures of tin-foil. When pushed in a certain distance their coatings come face to face with those on the outside of the glass tube. A pair of conducting rods with binding screws are attached to them and the cords for the patient are fastened to them. The capacity can be varied by displacing the internal armatures from their position in the neighbourhood of the outer coatings.

In France the name *franklinisation hertzienne* is often applied to Morton's method, and the opinion has been expressed by some writers that the discharges through the patient in Morton's method are oscillatory discharges of high frequency. Reference to the formula given below will show that this is improbable, because the resistance of the body is too high and the self-induction is too low to give the conditions necessary for oscillations in the circuit. Taking even the most favourable estimate of the resistance, the other quantities must differ considerably from those of the usual conditions of the experiment.

Mr. Rimington writing on this subject in the "Electrical Review" some years ago, calculated a case for a Leyden jar of about one pint in size, the capacity of such a jar being taken at ·0012 of a microfarad. He says, "suppose we take the resistance of the human body as 300 ohms, then the self-induction in the current must be greater than 27 microhenries to obtain oscillations, while the self-induction of the human body and the spark gap would be less than this. With a jar of greater capacity the case will be still worse," and we may add that with a higher figure for the resistance of the body, the case will be much more unfavourable to the existence of oscillations.

125. **Oscillatory discharges.**—The conditions which determine whether a condenser discharge shall be oscillatory or not were expressed mathematically by Lord Kelvin (then Sir William Thomson) in 1853.

He showed that the factors concerned were the resistance R of the circuit; its self-induction L and the capacity C of the condenser. Then if the resistance of the circuit is greater than the expression $\sqrt{4L/C}$ the discharge is a continuous one, but if the resistance is less than that quantity the discharge is oscillatory.

To illustrate the phenomena by analogy the behaviour of water in an hydraulic apparatus is commonly employed. Imagine two jars of water connected by a pipe in which is a tap. When the tap is open the jars are placed in communication so that water can flow from one to the other. With the two jars standing at the same level and the tap closed, one jar is filled with water and the other is left empty. This compares with the charging of the condenser. The tap is then opened suddenly and the water flows through the pipe, until finally a state of equilibrium is reached, with the water standing at the same level in both jars. This represents the discharge of the condenser. If the pipe of communication is narrow, there is resistance to the free passage of the water, and the flow is a continuous gradual one. If the pipe is a wide one the water flows rapidly and equilibrium in the two vessels is only reached after a series of oscillations in which the height of the water level is alternately greater in the first and in the second of the jars.

So again the discharge of a condenser has been compared to the vibration of a spring which has been bent and is let go. If free to move the spring reaches its position of rest only after a series of oscillations or vibrations. It comes to rest without oscillations if its movement is opposed by sufficient friction. In the case of the electrical oscillation friction is represented by the ohmic resistance of the circuit.

126. **General effects of static treatment.**—The effect of a static charging is to increase the frequency of the pulse and its regularity. The blood pressure is raised, the action of the skin is increased. Nutritive exchanges are accelerated. The effect on the nervous system is sedative, patients sleep better, and they may even show a tendency to fall asleep during the process of treatment. Treatment which is too prolonged may have an unfavourable effect.

In practical treatment it is found that some patients experience a marked feeling of improvement as soon as the charging begins, while others remain indifferent, or may even show by their words or movements that they find it uncomfortable. It is probable that this is due to the effect on blood pressure. Those whose pressure is low feel better as soon as it is raised, while those whose blood pressure is already high are made uncomfortable by the treatment.

Truchot* has reported the results of some experiments upon himself, in which he was charged once or twice daily for a week. Each charging period was of fifteen minutes duration, but it is not specified whether the charging was positive or negative. The points attended to were the pulse-rate, the temperature, and the urine; the force of the grasp was also determined by means of a dynamometer. These points were observed for the week preceding the commencement of the electrifications, and for the week which followed.

The pulse was increased in frequency after each charging, being raised from 65 to 80, but apart from this immediate effect there was also a gradual rise in the average daily rate so that after the fifth or sixth charging the pulse remained at 80 for the whole day, and only began to return to its normal frequency two days after the chargings had been discontinued, finally reaching its normal rate of 65 per minute at the end of a week. The temperature also showed a gradual rise, being 97·9 at the beginning of the treatment, and 99·3 at the end of the week, returning slowly to its former level during the next few days.

The strength of grasp was augmented by each charging, rising from 42 to 44 kilogrammes after the first time; from 41 to 43 after the fourth, and from 40 to 42 after the sixth, but, as these figures show, there was a progressive decrease in the muscular power during the week of treatment, and the decrease was gradually recovered from during the following week, when charging had been discontinued.

The analyses of the urine, though a little difficult to interpret, show at first an increased proportion of urea to total nitrogen, followed by an increase in the total nitrogen with a fall of urea, which Truchot interpreted by supposing that at first metabolism was increased and internal oxidation was improved, but that afterwards there was increased tissue waste with less perfect oxidation; here again the effects of the treatment were perceptible for several days after its discontinuance. His general condition showed increased appetite for the first day or two followed by a diminution; sleep became disturbed, and a feeling of languor and feverishness developed itself. Thinking that perhaps the season of the year (July and August), and the fatigue of the summer session might have contributed to his weariness, the experiments were repeated between Oct. 15 and

* *Archives d'électricité médicale*, Feb. 1894.

Nov. 15, after the repose of the long vacation. The results, however, were precisely the same, the temperature rose from 98·6° to 99° after four sittings. The pulse rose from 64 to 79, the feelings of fatigue returned.

The body weight does not seem to have been taken, and no light is thrown upon the question of the difference between the effects of positive and negative poles.

Of more importance than the experiments last noted are the numerous clinical results which are observed in the treatment of various forms of general or of nervous debility. Vigouroux, Imbert de la Touche, Monell and others, all report strongly on its value in cases of neurasthenia in its various forms, and in the treatment of insomnia and mental fatigue ; and he quotes from several recent writers on the subject of the treatment of certain forms of insanity and morbid mental states in which favourable results have followed statical applications, particularly in melancholia. In the nervous disturbances which occur about the time of the menopause, decided benefit may be obtained from simple static charging with the use of the negative breeze.

Statical applications undoubtedly act upon the function of menstruation. With patients receiving a course of treatment for conditions quite unconnected with the generative functions it is common to remark some effect upon the menstrual periods. Professor Doumer,* of Lille, has published his notes on 400 women treated by static electricity. In 342 the uterine functions were quite normal; in the rest, 58 in number, there was some complaint of menstrual trouble, mainly of the nature of dysmenorrhœa. Among these patient there was a hastening of the commencement of the period in 68 per cent., and an increase of the flow in 77 per cent. Among the 400 cases there were 178 who had some pains or discomfort about the date of the commencement of their periods, and 73 per cent. of these, 130 persons, were relieved of these symptoms, while the remainder were not. Menstrual irregularity was present in 51 cases and quickly disappeared in 31. These results followed for the most part upon simple electrostatic charging, but the breeze or the roller applied to the lumbar region produced a more prompt result.

127. **Local applications.**—When the static machine is used

* *Archives d'électricité médicale*, 1897, p. 96.

for the production of local effects, the action depends very greatly upon the peculiar stimulation of the sensory nerves of the skin which can be produced by local applications with the different forms of electrode.

With the point electrodes these sensory impressions can be made to vary from a cool and gentle breeze effect to an intensely pungent pricking, and much of the success of static applications depends upon the adjustment of the degree of cutaneous stimulation to the nature of the individual case. Much of the value of the machine for the relief of painful states lies in this wide range of sensory effect and in its peculiar qualities.

The effect of breeze discharges upon pain in the superficial cutaneous nerves, as, for example, in headache, or neuralgia, or in painful neuritis, is very striking. Care must be taken when treating patients for the relief of pain, not to spoil the effect by accidental sparks or shocks. With the negative point (the patient charged positively) there is not so much risk of this, for sparking does not occur under these conditions, except with the point at very close quarters. If for any special reason the patient is negatively charged, and the point therefore is positive, sparks may occur even across a distance of four inches or more, and must be guarded against.

The action upon the skin of a strong brush discharge through woollen clothing remains plainly visible for some hours afterwards, in a persistent reddening or in the form of urticarial elevations.

The most intense cutaneous stimulation is that produced by the roller electrode ; and the severity of this mode of application demands that it shall be used only for brief periods of a few seconds at a time. Attention must also be paid to the thickness of the layer of clothing over which the roller is moved, as the sparks will be longer and stronger with a thicker layer. In approaching the roller to the patient, a quick movement is necessary, as there is a tendency for stray sparks to pass as soon as the roller comes within striking distance. This tendency can be reduced by partially discharging the patient until the roller has come into contact with the patient. This is effected by placing one foot on the platform.

In addition to the effects produced by the brush discharge, and by the roller upon the sensory nerves of the skin, we may

employ the shock or commotion of the strong muscular contraction, which is produced by the application of a spark from the knob. This shock relieves many deep seated pains of a myalgic nature, and often relieves them instantaneously. Probably it acts, in part at least, by a sort of forcible wrenching of muscle fibres. Often it is useful to request a patient with a pain in a muscle, to assume the attitude which provokes or increases the muscular pain, and then to apply the spark or sparks to the painful part. In lumbago, in deltoid rheumatism, and other so-called rheumatic muscular pains, the treatment by sparks relieves promptly.

The local action of static discharges upon the skin is shown by its effects in certain skin diseases. It has been frequently noticed by others, and it has also come under my own observation, that frequent applications of the brush discharge to the scalp seem to stimulate the growth of the hair. In pruritus, which is so often intractable to many forms of treatment, in psoriasis, in eczema, and in varicose ulcers of the leg, the brush discharge is often efficacious.

Among the observations on statical treatment which have recently excited fresh interest, are some which seem to show that the brush discharge of the statical machine has a curative effect upon cutaneous affections of very various kinds. Thus Macintyre of Glasgow in a presidential address to the British Laryngological Association in November, 1901, relates some trials of the static machine in lupus, tubercle, rodent ulcer, and epithelioma. The cases tried were mostly persons with one or other of these diseases in some accessible part of the respiratory tract; the method was to insulate the patient who was charged negatively, and to bring near the affected region a blunt point or small ball, which was connected to the positive side of the machine.* The effect was to produce a strong brush discharge playing upon the affected part, and the results of the treatment were good in a number of cases. I have myself seen decided improvement in a rodent ulcer as the result of static brush discharges (negative point) applied to it, and in another patient with a large cancer in the breast I have also seen a reduction of size and relief of pain lasting several months.

In this connection it is interesting to note that Cavallo, in 1790, says that a patient with cancer of the breast was so far

* *Journal of Laryngology*, December, 1901.

relieved (by the brush discharge), that the pains she had suffered from for years almost disappeared.

Albert Weil has reported a case of lupus of the thigh cured by the brush discharge and static sparks.*

When one comes to search for an explanation of these effects, one's attention becomes drawn to the probability that the active agent is to be found in the kathode rays which are emitted from bodies which are negatively charged.

Many observers believe that, with the static machine, it is the negative pole which acts most effectively upon superficial affections. If kathode rays are the active agents, one can readily understand why this should be the case, because their action would be mainly upon the surfaces upon which they were projected. The similarity of effect which has been observed between static discharges and X rays in some of their medical applications, is of great interest, even if it should prove that the former are relatively feeble.

Though kathode rays and X rays differ from one another considerably, yet they have many points in common, and it is not impossible that their effects upon the body may be comparable. Certainly it appears probable that in the future we shall have to reckon with the action of kathode rays in all treatment by high potential discharges, whether they be generated by the static machine or by the high frequency coil. It is even possible that by and by we shall prefer to speak of "treatment by kathode rays," where now we say treatment by "effluve" or by negative brush discharges. The time is now ripe for direct experiments upon the use of kathode rays in medical work.

* *Progrès médicale*, 1900.

CHAPTER VII.

Electricity of High Potential. High Frequency. Phenomena.

Frequency of oscillations. Medical apparatus. The resonator. The Tesla transformer. Practical methods. Physiological effects.

128. **High frequency.**—We have already seen (§ 125) that when a charged conductor is discharged, it happens under certain conditions of the discharging circuit, that the discharge is an oscillatory one. The oscillations die away very quickly, but while present they may have a periodicity of hundreds, of thousands, or of millions, a second. The rate of oscillation is determined by the nature of the circuit. With small capacities and with small self-inductions, the rate of oscillation is more rapid than with large values of either of these components.*

For the most rapid oscillations circuits should have small capacities, low self-inductions, and very low resistances. Increasing the capacity or the self-induction slows the rate of oscillation, and increasing the resistance damps the tendency to oscillation, so that any increase of resistance above a certain critical value will altogether damp out the tendency to oscillation.

A most lucid exposition of this subject will be found in Lodge's "Modern Views," Lecture 3, on "The Discharge of a Leyden Jar." This should be studied by everyone who intends to use high frequency apparatus. Sir Oliver Lodge has pointed out that it was Joseph Henry, of Washington, who first arrived at the conviction that the discharge of a Leyden jar was oscillatory, and he quotes the following remarkable words of Henry :—

* The formula for determining the time T of oscillation is as follows:— $T = 2\pi\sqrt{CL}$, when the resistance of the circuit is very low, as is the case in the solenoid of a high frequency apparatus (fig. 93). When the resistance is high the equation becomes the following:—$T = \dfrac{2\pi\sqrt{CL}}{\sqrt{1-\dfrac{CR_2}{4L.}}}$

"The phenomenon requires us to admit the existence of a principal discharge in one direction, and then several reflex actions backward and forward, each more feeble than the preceding, until the equilibrium is attained."

Of late years Elihu Thomson, Nikola Tesla, and D'Arsonval, have developed the study of these "high frequency" phenomena, and have obtained some remarkable results. The apparatus required is comparatively simple; the principle is to charge Leyden jars whose outer coatings are connected by a helix of wire, or solenoid, as in fig. 92. The inner coatings of the jars terminate in knobs, whose distance apart can be

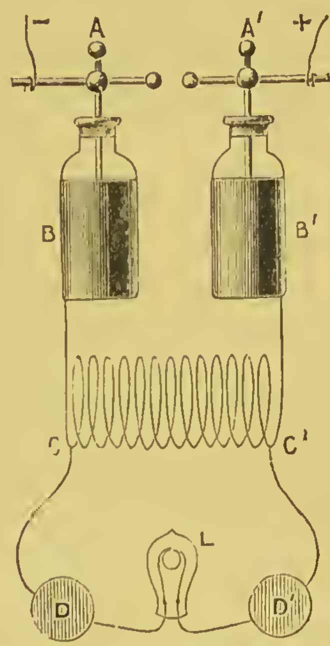


FIG. 92.—Arrangement of apparatus for high frequency experiments.

adjusted to suit the sparking distance of the charging electromotive force. The jars can be charged from a Wimshurst machine or from an induction coil of large size, or, through a high potential transformer, from the alternate current supply mains. The output is least in the first method.

The jars when charged to a sufficient potential, discharge in an oscillatory manner across the air gap and through the solenoid connecting the outer coatings, and the latter becomes the seat of electromagnetic induction effects, comparable to those of the primary circuit of an induction coil, so that a

derived circuit formed by wires leading from the two ends of the helix yield a current, as do the wires of the "primary current" of a coil. In fact the apparatus may be regarded as a modified induction coil, the exciting current being supplied from the discharge of the jars instead of from a voltaic cell, while the spark gap takes the place of the contact breaker. The suddenness of the discharge causes the changes in the magnetic field of the circuit to be very rapid, and consequently (§ 53) sets up very powerful induction effects, both in the solenoid itself (self-induction), and round it by mutual induction, and a secondary coil wound over the solenoid gives very conspicuous effects. Figure 92 shows an arrangement, due to D'Arsonval, for demonstrating high frequency effects. D, D′, represents two persons holding between them an incandescent lamp L, and having their other hands connected to the terminal points of the solenoid; under these conditions the current between C and C′ traverses the lamp and the arms of the two experimenters, and the lamp glows brightly, though they feel no shock.

The solenoid is usually made of about twenty turns of thick copper wire. Although the true ohmic resistance of the whole helix is excessively low, only a very small fraction of an ohm, its impedance or virtual resistance to these very rapidly oscillating currents is so high, that if two neighbouring turns are approached by a finger there will be strong sparking from one turn to the next through the alternative path offered by the finger tip, in spite of the relatively enormous ohmic resistance of the latter; and if a straight or slightly bent piece of copper wire be brought near to the two ends of the coil, loud crackling sparks will leap to it. Professor Fleming* in dealing with this matter says:—"If the difference of potential between the ends of a conductor is established with great suddenness, the resulting electric flow is less and less determined by what may be the true resistance, and more by the inductance of the conductor. We have a mechanical analogy in the case of impulses or sudden blows given to heavy bodies, which well illustrates how strikingly force phenomena may be altered, when for steady or slowly varying forces we substitute exceedingly brief impulses or blows.

"If an explosive, such as gun-cotton, is laid on a stone slab in open air and simply ignited, it burns away with comparative

* "The Alternate Current Transformer," Vol. i.

slowness, the slab is uninjured, and the evolved gases simply push the air away to make room for themselves. But it is well known that by means of detonators the same explosive can be fired with enormously greater rapidity, and in this case the blow or impulse given to the air is so sudden that it has not time to be pushed away, and its incapability of receiving a finite velocity in an infinitely small time bestows on it an inertia resistance, which causes nearly the whole of the effect of the explosion to take effect downwards on the slab, and this last is shattered. The inductance of conductors introduces a series of phenomena which are the electrical analogues of the above mechanical experiment. A conductor of sensible inductance can no more have a current of finite magnitude created in it instantaneously, than a body of sensible mass can have a finite velocity instantaneously given to it. In both cases there is an immense resistance to very sudden change of condition. Accordingly, the study of the behaviour of conductors under exceedingly sudden electric blows or electromotive impulses leads us to consider some very interesting effects."

129. **The "skin effect."**—Another point of importance in the phenomena of high frequency currents, is one which is commonly spoken of as the skin effect. By this is meant that, with rapidly varying currents, the distribution of current in the thickness of a wire conductor is irregular. Silvanus Thompson in writing on this point says that with rapid frequencies the currents do not flow equally through the cross-section of the conducting wire, but are confined mainly to its outer surface. He mentions that even at a frequency of 100 per second, the current at a depth of 12 millimetres from the surface is (in copper) only about one-seventh of its value in the surface layers. In iron wires the depth of the skin for one-seventh value is about one millimetre. For such rapid oscillations as the discharge of a Leyden jar, where the frequency is several millions, the conducting skin is probably less than one-hundredth of a millimetre thick. Hollow tubes in such cases conduct just as well as solid rods of same outer diameter. The conductance is proportional not to section but to perimeter.

In some experiments of Sir Oliver Lodge,* two wires of very different thicknesses were taken, each wire was about 100 inches long and was bent into a single circle. One had an ohmic resist-

* "Lightning Conductors and Lightning Guards."

ance of 2·6 ohms, and the other of ·004 ohms; thus one had a resistance 650 times greater than the other. The virtual resistances of the two wires, for rapidly varying currents, were very different from their true ohmic resistances, and their relative conductivity for these currents was also very different from their relative conductivities with steady currents. The resistances were found to be 4 and 6 ohms with oscillations at the rate of a quarter million per second, 43 and 78 ohms at three million oscillations, and 180 and 300 ohms respectively at twelve million oscillations.

130. **Magnitude of high frequency currents.**—That the currents, which flow through the experimenters' bodies and the lamp in D'Arsonval's experiment, are really large, must be accepted. It is less easy to say how large they may be. Their apparent magnitude certainly varies with the magnitude of the apparatus used. As measured by means of a hot wire ammeter, they may give readings corresponding to 100, or even up to 500 milliampères or more of steady current. There are difficulties in understanding why they should produce such slight physiological effects, and various explanations have been put forward, but none appear quite satisfactory. Although the currents may not have the values indicated by the ammeters, it is at least certain that there is an expenditure of a number of watts (§ 29) in the circuit, for this can not only be measured in a hot wire instrument (§ 84), but might even be recovered in the form of work, if it were thought worth while to devise an apparatus for the purpose.

The subject was discussed freely in the Electrical journals about ten years ago. In the *Electrical Review* the Hon. Charles Parsons is quoted as saying that a 100 volt lamp taking ·6 ampère to bring it to incandescence with a steady current, would incandesce equally well with ·006 ampère of mean current, if subjected to short impulses at 10,000 volts.

With this explanation it is necessary to admit that the current must reach maxima approaching 20 ampères, and this of course increases the difficulty of explaining the absence of physiological effect.

Although it is a fact that with a high frequency apparatus no shock is felt when the hands are in good contact with the electrodes, yet if there be an air gap in the discharging circuit the shocks at once become felt, and the wider the gap the more

severe are the shocks. This observation is not alluded to in the published accounts of D'Arsonval's experiments. Hedley has shown that if the electrodes in contact with the skin are progressively diminished in area a point is reached with small sized electrodes, when a distinct sensation becomes perceived, and he has very rightly argued that if the rapidity of alternation be the only factor which makes the current imperceptible, it should be as little felt with electrodes of small surface as with those of large surface.

The progressive increase of sensory effect as the area of contact is diminished, would seem to suggest that the concentration or density of the current is an important factor, and this again would seem to imply that the total actual current flowing must be one of small magnitude.

These paradoxical effects have given rise to much discussion, but further investigation is necessary before the real explanation of them can be arrived at.

The "skin effect" has been invoked to explain the absence of sensory and muscular effects with high frequency discharges. It has been said that the current passes only by the superficial layers of the epidermis and does not penetrate into the body at all, and that it is not felt on this account. The physiological effects produced by high frequency discharges would suffice to combat this theory. Moreover, high frequency currents not perceived by human beings are able to kill small animals in a few seconds. The "skin effect" observed in a good conducting material like a metallic wire is not nearly so definite in conductors like the human body.

Our information respecting the behaviour of conductors such as the human body to high frequency oscillations is still quite imperfect, and it is probable that the electrical oscillations set up in the human body are quite unlike those produced in a metallic conductor.

When a conductor of high resistance, such as the human body, is connected to two points on a helix at which very rapid changes of potential are occurring, the conductor must be subject to pulses of changing potential tending to set up oscillatory currents of high frequency. For a proper knowledge of the effects actually produced in the body under these conditions it is necessary to consider the effects of the resistance of the body and of its capacity. The high resistance of the body would

tend to exercise a very great damping effect, and the capacity would also tend towards a distortion of the waves of current which might profoundly modify the oscillatory character of the current through the body, even though the applied electromotive forces were oscillatory, and of high frequency.

It must be borne in mind that all high frequency effects studied upon human beings have been made with the subject in shunt to the high frequency circuit. The patient is not in the direct circuit of the jars, and owing to the body resistance, it would be very difficult to produce high frequency oscillations in the body when it was so connected. From experiments which have been made in this direction it appears not merely probable,

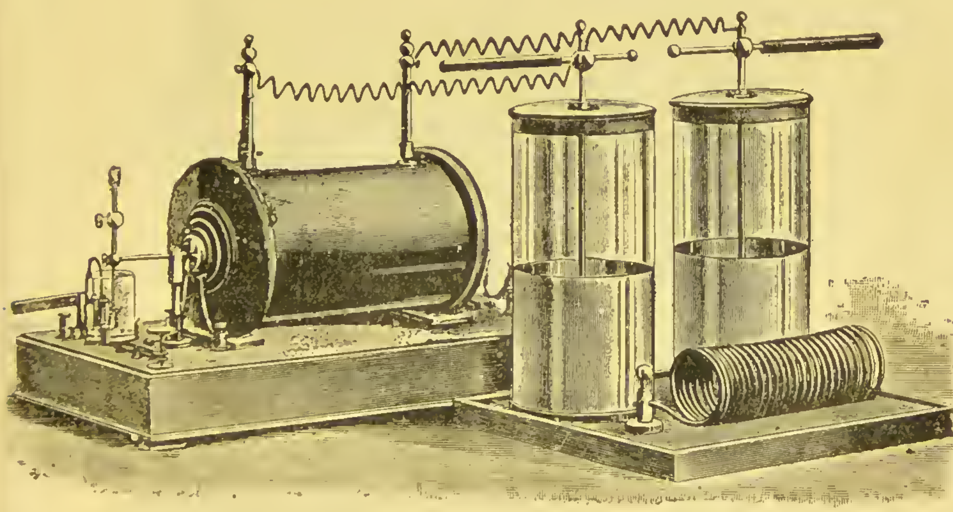


FIG. 93.—D'Arsonval's high frequency apparatus, showing Leyden jars with the outer coatings joined by a solenoid and the inner coatings fed by an induction coil.

but certain, that such oscillatory discharges which could be produced by arranging the circuit in accordance with the formula given in § 125 would be quite painful.

131. **Medical applications.**—The development of high frequency apparatus for medical work has taken place almost entirely in France, and is based upon the physical and physiological researches of D'Arsonval. The current from the primary helix is that most commonly used in medical applications, and the arrangement shown in fig. 93 represents the apparatus in a simple form. The solenoid connecting the outer coatings of the jar is of bare wire, open to the air, as this affords sufficient

insulation for most purposes. If a secondary coil is to be used it may be immersed in a vessel of insulating oil, or may be so wound as to leave a large air space separating it from the primary; the latter may be placed either inside or outside the secondary (fig. 94). No iron core is used.

The methods of applying high frequency currents to the human body which were devised by D'Arsonval will be found

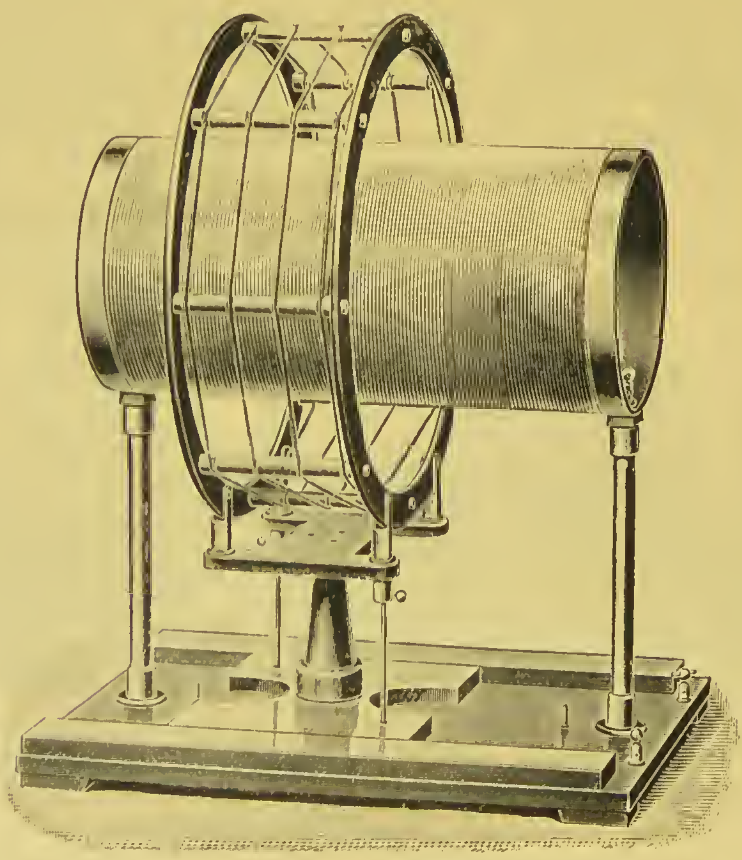


FIG. 94.—High frequency transformer. The secondary coil is wound on the ebonite tube and the primary consists of the four turns of wire seen outside of it.

in a paper by him in the *Annales d'électrobiologie*, for January, 1898, in which a summary of his previous work is given in a simple form. Three modes of application were originally proposed. In the simplest of these the patient is put in direct connection with the extremities of the helix or solenoid, the electrodes used being the ordinary moistened pads already described (fig. 41) or some modification of these. They should

be of large surface, and must be kept in good firm contact with the skin to prevent sparking and consequent burning at the points of imperfect contact. This method is commonly spoken of as the direct application of high frequency currents.

The second method is by "condensation" or the condenser couch. The patient is connected to one end of the solenoid in the ordinary way, but the other end is attached to a large plate of metal brought near to the patient, but insulated from contact with him. Thus the metal plate and the body of the patient form the armatures or coatings of a condenser arrangement having a large electrical capacity, which is alternately charged and discharged as the potentials at the extremities of the solenoid vary. The apparatus is usually arranged in the form of a couch (fig. 95), the patient lies upon insulating cushions

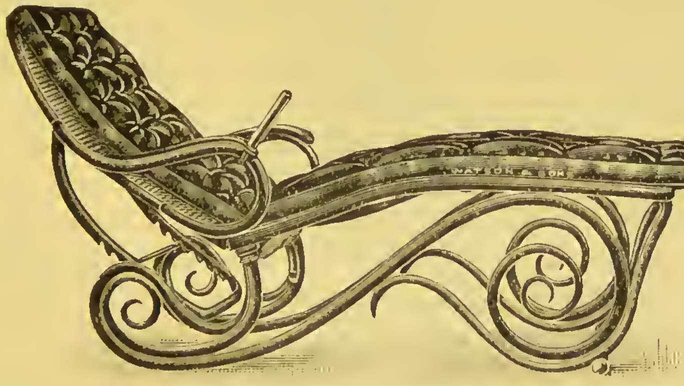


FIG. 95.—Couch for condensation.

which separate him from the metal sheet which is fixed beneath. The current passes to the patient either by a handle of bare metal held in the hand, or it may be in the form of an electrode applied upon any desired part of the body.

Another mode of application consists in enlarging the size of the solenoid and enclosing the patient inside it. The patient does not touch any conductor, but is acted upon inductively by the currents in the solenoid which is carrying the Leyden jar discharges. The currents generated in the patient by induction are considerable, so much so that an incandescent lamp held between his two hands is brightly illuminated. This method is called treatment by auto-conduction. Horizontal solenoids enclosing a couch are made, and also vertical solenoids in which a patient can stand or sit.

In all three methods the applications are general rather than local, the whole body is placed under the influence of the currents, and they may therefore be regarded as methods of general electrification. The physiological effects upon which their medical applications are based are the very marked increase of metabolic activity which has been observed in experiments with high frequency currents upon animals, and upon men; thus D'Arsonval reports the output of CO_2 in the case of a human being as being raised from 17 litres to 37 litres per hour. Associated with this there is a considerable increase in the production of heat, namely from 79 calories to 127 calories per hour, the body temperature remaining steady at a normal point.

Other physiological effects which have been noted are a superficial analgesia or anæsthesia of the skin in contact with the electrodes, and a decrease of excitability of the nerves and muscles in the neighbourhood; there is a tendency to relaxation of the peripheral vessels, blood pressure is lowered, the amount of nitrogen and of phosphoric acid excreted in the urine is also increased.

The field of treatment in which high frequency currents seem to be especially indicated is that of diseases due to nutritional failure (*ralentissement de nutrition*) such as gout, rheumatism, diabetes, obesity, debility.

The method is essentially a method of general electrification and the results it gives are somewhat similar to those obtained with the statical machine already described or with the electric bath, which will be described later. Each of these methods has its special advocates, but the selection of one or other for use will depend a good deal upon the resources of the individual medical man. Thus one will have special conveniences for an electric bath, another will find a static machine more suitable, and so on. Good work can be done by all the modes of general electrification, and the high frequency methods of D'Arsonval have not as yet been shown to possess any conspicuous advantages over the others.

132. **Local effects.**—High frequency applications have also been used for local effects, particularly in the form of brush discharges. In order to develop these brush discharge effects as far as possible it is necessary to obtain potentials as high as possible. This may be done by the use of a secondary coil, oil

immersed or air insulated, or by an application of the principle of syntony or "resonance." Oudin, in 1892, designed a "resonator" composed of an open solenoid of wire which could be connected up as an extension of one end of the solenoid of a high frequency apparatus, and served when carefully adjusted to raise the potential to such an extent that a long brush discharge could be obtained from its other or free extremity. Oudin's resonator is now in general use for the production of high frequency brush discharges, and these have been shown to have so great an utility in the treatment of various affections of the skin and mucous membranes that they have added an

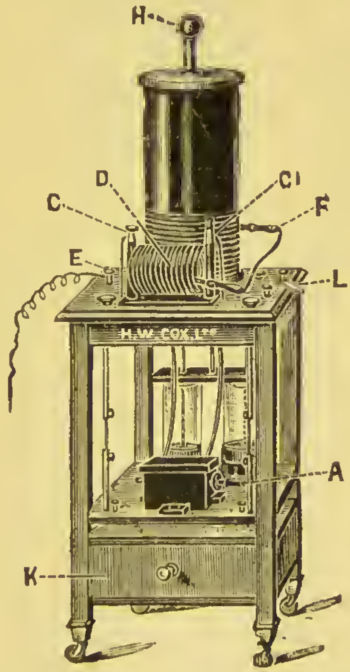


FIG. 96.—Arrangement of high frequency apparatus.

important field to the medical applications of high frequency currents. The secondary coil illustrated above (fig. 94) can be used instead of Oudin's resonator. When the effluve from the resonator is used the other extremity of the solenoid (proximal extremity) is connected to earth.

133. **Description of apparatus.**—Although high frequency currents can be produced with the static machine, or with apparatus connected to the alternating mains, the instruments in common use for the purpose are almost universally worked from Rhumkorff coils. There has been so much activity in

connection with high frequency work in recent years, that manufacturers of electrical apparatus make high frequency sets in various patterns, and an examination of their catalogues will enable anyone to see how these differ in detail from one another, and to choose the form of instrument which most takes his fancy.

A very convenient arrangement is that shown in the accompanying figure (fig. 96). On the lower table or platform there are the two Leyden jars. Their inner coatings are connected to the secondary terminals of an induction coil, and also to a spark box, A, of glass, inside which the discharges take place between two metallic knobs, whose distance apart can be adjusted by a handle. The object of the box is to diminish the sound of the sparks, which is loud and disagreeable. The outer coatings of the jars are connected together through the solenoid, D, on the upper table. C, C′, at the extremities of the solenoid, have sockets for the attachment of the conductors, which convey the current to the patient. F is a flexible wire with clips for connecting the solenoid to the resonator, which consists of a large spiral coil of wire wound on a frame and terminating above at H.

134. **Oudin's resonator.**—The upper two-thirds of the resonator are covered by a cylinder of ebonite, while the lower part is left uncovered. This is necessary because the point of attachment of the solenoid to the resonator has to be found by experiment, and varies for different applications. If trial be made with the clip of F attached to the resonator wire at various points, it will soon be seen how great an effect may be produced upon the brush discharge from the top of the resonator, by slight alterations in the point of attachment of the clip. When properly connected there will be a long divergent brush discharge from the knob H, as soon as the coil is set in operation. The adjustment of the clip to the best position on the resonator wire is the tuning of the resonator, and it is an instructive experience to tune the apparatus under different conditions. For instance, if the position for producing the longest brush discharge be first determined when no patient is connected to the machine, it will be found that the attachment of a patient will throw the apparatus out of tune, and will reduce the length of brush discharge very considerably. If the position of the clip be altered, the best position can again be picked out,

and when found, the brush discharge will again become as long as before.

It is by no means necessary to have the solenoid separate from the resonator. One large solenoid may be used, as in fig. 97. In this case the lower turns of the wire form the solenoid proper, while the upper turns form the resonator. The frame and coil is made to rotate on its axis, and in doing

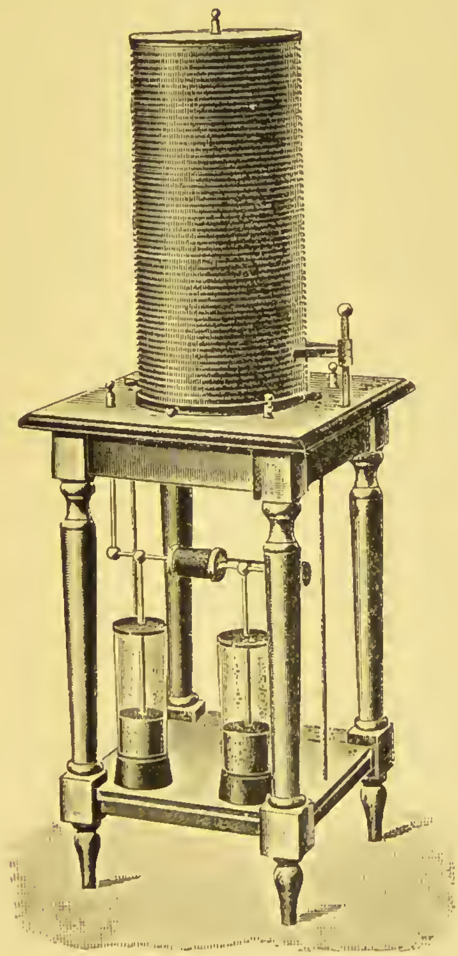


FIG. 97.—High frequency apparatus.

so the number of turns included in the direct discharging circuit of the jars, and the point of junction between solenoid turns and resonator turns can be easily varied by means of a sliding contact brush or roller, as shown, which rises or falls on its support if the cylinder is rotated, as the spiral wire in travelling past the contact acts like the thread of the screw. The plan of the

resonator is shown in fig. 98. The outer coatings of the Leyden jars, C C, are connected to two points on the solenoid, D; the part thus included in the circuit forms the solenoid proper and is traversed by the discharge current of the jars, the remaining turns form the resonator. The position of the contact is capable of variation as just described.

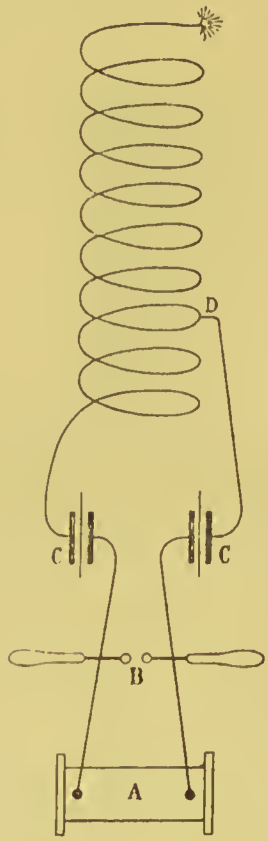


FIG. 98.—Plan of resonator. A, coil. B, spark gap.

135. **Electrodes.**—For direct applications and general effects the electrodes described in § 76 should be used. They should be moistened, must be in good contact, and must not be too small. In high frequency applications the magnitude of the currents used is large, and if the contacts with the body are small, there is likely to be a local effect on the skin in the form of burns. The same result will follow if the contacts are imperfect, and the current passes to the patient in the form of sparks. Bare metal may be used for the electrodes provided the contacts with the body are thoroughly good and large; thus

a metal cylinder held in the hand is often used for an electrode, as is seen in fig. 95, where a metal electrode of this kind is shown affixed to one of the arms of the couch.

In local applications of high frequency the spark or brush effect between the electrode and the skin is made use of for purposes of treatment, and a number of special electrodes have been devised for local use. Of these the simplest is composed of a number of metallic points very much like the multiple point electrode described in the chapter on Static Electricity (fig. 89). Other forms of electrode for local effects have the form of closed glass tubes of different shapes and sizes. They are filled with water or with salt solution, or else they are exhausted and sealed to give them a conducting vacuum internally. A wire through the glass forms the connection between the conductor and the interior of these electrodes. Often they are provided with a glass handle, or in place of this they may

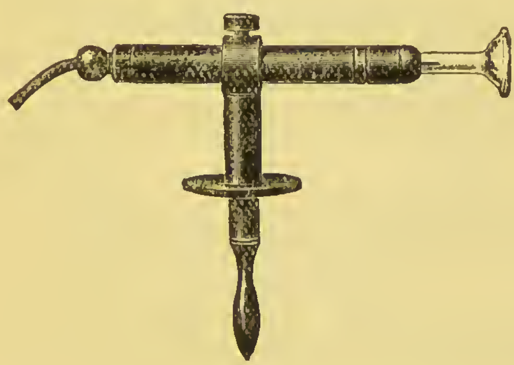


FIG. 99.—Electrode holder of ebonite.

be fitted with a metal cap at one end for attachment to a socket in an ebonite handle.

If the finger be approached to one of these glass electrodes when connected to the apparatus, a violet brush discharge will be seen between the glass and the finger. This discharge does not come from the inside of the tube, but it is produced at its outer surface by induction (§ 10). It corresponds in polarity and in magnitude with the current flowing to the inner surface of the tube from the wire. If the finger be kept in one position for some little time a sensation of heat will be felt in the skin of the finger, and it can easily be shown that there is an actual production of heat by the discharge. The better the contact between the glass and the skin the less will be the amount of

brush discharge and of heat produced. In applying high frequency currents locally the luminous and thermal effects just described play an important part. Careless use of the electrodes may blister the skin. In using the multiple point electrode to give a brush discharge care must be taken not to approach the electrode too near the skin, otherwise sharp cracking sparks will pass to the patient and produce a painful effect, and if repeated several times they may cause small burns, whereas the pure brush discharge is not at all painful. The glass tube electrodes with partial vacuum present an attractive appearance when in action, as they are luminous from the discharge of the current through the vacuum which acts as a conductor. The

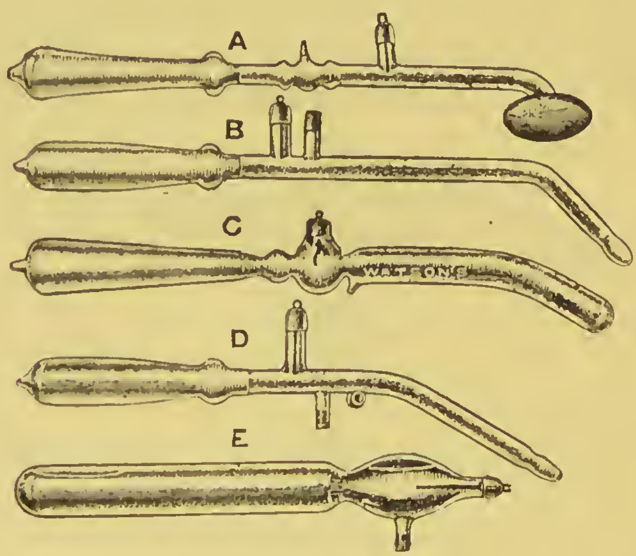


FIG. 100.—Glass electrodes.

luminosity of the gas is due to its incandescence and tends to heat the glass wall of the tube, and these tubes occasionally crack from this cause. They may also be punctured by a spark, and if this happens the sparks which traverse the crack or puncture produce a disagreeable effect upon the patient, so that the application must be stopped and the tube replaced by another one.

For some purposes tubes exhausted to a very high degree are useful. At exhaustions comparable to those of a Crookes tube the phosphorescence of the glass becomes evident, and such a tube is a source of X rays, and has been used on that

account for internal applications where an ordinary X ray tube is inapplicable.

136. **Graduation and measurement.**—The strength of the applications can be graduated by regulating the current from the induction coil used to supply the Leyden jars, and by alterations in the width of the spark gap. Further, the number of turns of the solenoid which are in parallel with the circuit of derivation may be varied. Sometimes this is done by a spring clip, which may be attached to the solenoid at any desired point, and sometimes by a copper rod, which slides along the inner sides of the turns of the solenoid and short circuits some of them. If the coils of the solenoid and of the resonator form one single spiral, as in fig. 97, the changing of the point of contact

FIG. 101.—Hot wire milliamperemeter for measuring high frequency currents.

has the effect of varying the number of spires constituting the solenoid proper, and so permits graduation to be effected.

For measurement, hot wire instruments (fig. 61) are used. Fig. 101 gives an illustration of the form of instrument in common use.

The magnitudes of current used in high-frequency applications range from 50 or 100 milliampères up to 500, or even more. Many operators believe that very large currents should be used if the best results are to be secured.

The galvanometer should be placed in series with the patient when direct applications are used, and between the patient and his point of attachment to the solenoid when treatment is given on the condenser couch. With the method of auto-conduction,

measurements of the actual currents circulating in the patient's body cannot be made. Generally it is necessary with this mode of treatment to operate the instrument to its full power. When brush discharges are used, measurement of current is less needed, as the appearance of the effluve is a guide, but the milliamperemeter may be connected to the top of the resonator.

In all applications of high frequency it is desirable to have a regular action of the interruptor mechanism of the induction coil. On this account a mechanical interruptor is to be preferred to the vibrating hammer type of break. Electrolytic interruptors, by reason of their smoothness of action and the very rapid rate of interruption which they afford, are very suitable for high frequency work, especially if currents of large magnitude are required. A ten inch or twelve inch coil should be employed to feed the Leyden jars of the high frequency apparatus.

137. **The alternating mains for high frequency.**—The high frequency apparatus is almost always operated from a large induction coil, and practically all the experiences which have been acquired in medical work have been with the apparatus worked in this way. High frequency effects can be produced equally well by means of a step up transformer, and in places supplied by alternating current electric light mains, this plan would seem to offer substantial advantages in point of simplicity of apparatus. There are certain differences in the nature of the currents produced. When an induction coil is used, the electromotive forces in the Leyden jar circuit are generally very high, and the capacity of these condensers is small. With the step-up transformer the condition is reversed, for the electromotive force available is lower, while the capacity permits of large increase. The discharges through the solenoid under these latter conditions would oscillate less rapidly, though the amount of current set in motion would be greater. It is probable that for all applications of high frequency, except those requiring a brush discharge, the effects yielded by both types of apparatus would be identical, and the transformer fed from the alternating mains would have the advantage of greater regularity of working. When brush discharge effects are tried, the difference between the two types of apparatus becomes easily apparent, and the brush obtained from the top of the resonator is much less soft and diffused on a transformer system than it is with the

coil. This difficulty probably depends upon the greater magnitude of the current in the case of the transformer, which implies a correspondingly greater tendency to spark or to arc across to

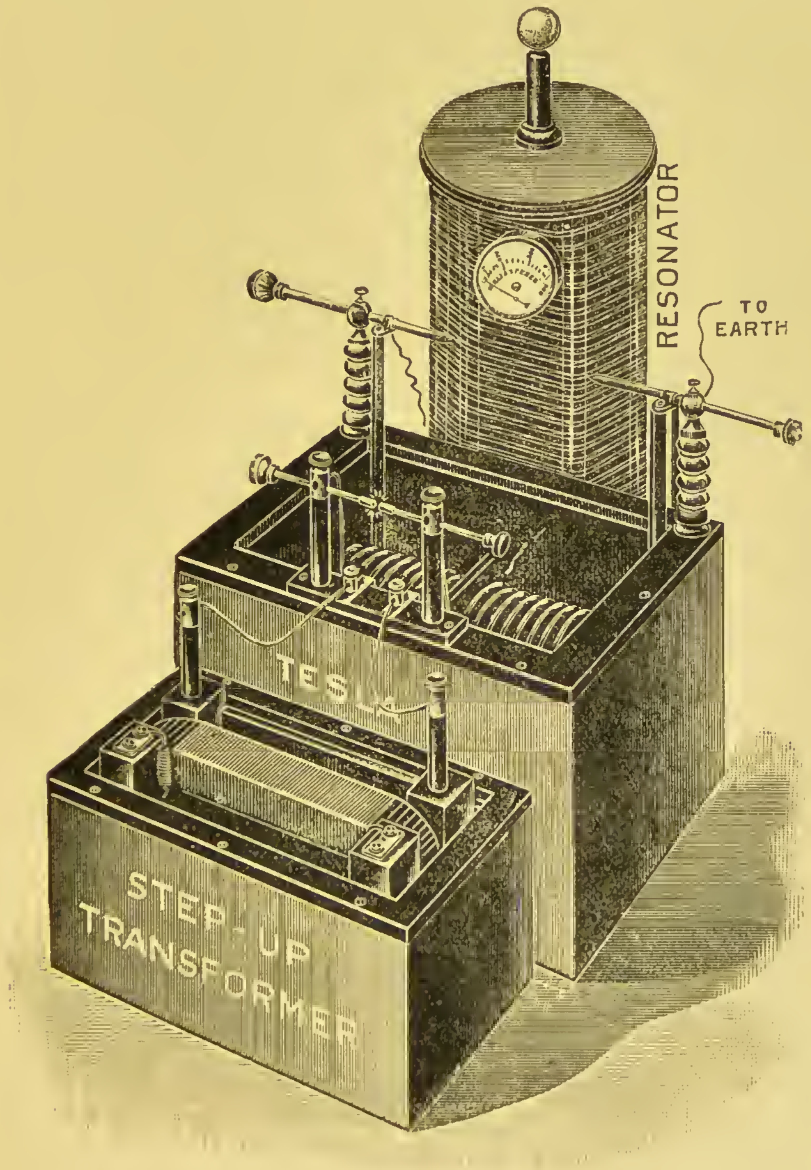


FIG. 102.—Apparatus for producing high frequency currents for alternating mains.

the patient, whereas the coil driven apparatus with a smaller current would tend to give only a brush discharge.

If the resonator be modified in such a way as to greatly

increase the electromotive force, this difference between the two types of apparatus should tend to diminish, and this has been found to be the case in an apparatus constructed by Mr. Leslie Miller at my suggestion. In this apparatus (fig. 102) the resonator is twice as high as usual, and has twice as large a diameter, and consequently contains a much greater length of wire. With this apparatus a smooth soft effluve can be obtained, and the general behaviour of the apparatus is rendered very nearly the same as that which obtains with a resonator of the ordinary size operated by an induction coil. In working from the alternating mains precautions are necessary to protect the patient from the currents of the transformer circuit. Several methods have been proposed for this, but the safest is to use two condensers, just as two Leyden jars are used in working from a Rhumkorff coil.

138. **Uses of high frequency currents.**—A copious literature has grown up of recent years around the subject of high frequency treatment. Denoyés in his work gives a bibliographic index of writings on this branch of electro-therapeutics, which occupies nearly seven pages. Those wishing to go more fully into the details of high frequency work should consult this book,* in which the subject is ably and exhaustively treated.

High frequency applications are of decided value as a therapeutic method, and in due time they will occupy a well deserved place in electro-therapeutics. At the present time high frequency is being overdone in this country. It has fallen into improper hands, and is being extensively abused. It is exploited by syndicates, by municipal bodies in health resorts, by the proprietors of nursing homes and massage institutes, and by others in places where "treatments" are administered by unqualified people. It is advertised by means of placards in public places, and vacuum-tube effects and rubbishy clap-trap about the enormous voltages which can be safely applied to human beings by its aid are used to impress an ignorant public. It is being applied indiscriminately to the treatment of all kinds of morbid conditions, and has been prematurely and injudiciously recommended for the cure of cancer, of diabetes, of pulmonary phthisis, of chronic rheumatoid arthritis, of gout and rheumatism, of many uterine diseases, of gonorrhœa, and

* Denoyés, "Les Courants de Haute fréquence; propriétés physiques, physiologiques et thérapeutiques." Paris: Baillière et Fils, 1902.

of a host of other ailments. Under these circumstances it is only natural that high frequency treatment should be condemned by many who have not the time to examine it for themselves.

139. **General effects.**—In addition to the physiological effects upon the respiration, the circulation, and the production of heat which have been described by D'Arsonval, there is a general sensation of stimulation and of increased vigour on the part of the patients submitted to high frequency treatment. A feeling of warmth, and even an actual perspiration, is not uncommonly observed. The effects of auto-conduction, of auto-condensation and of direct (bipolar) applications are practically identical. As the first method requires a cumbrous apparatus or solenoid large enough to enclose the whole patient, it is not used so widely as the more convenient method of the condenser couch. Bipolar applications may be preferred when some definite region of the body requires special attention, as for example the hip and thigh in cases of sciatica, but most high frequency treatment is given by means of the condenser couch for general applications, and by the effluve for local treatments.

There is no doubt that high frequency treatment exercises an influence upon the course of a certain number of morbid states, although in many of these its influence for good is not of any particular degree of excellence. In the field of general diseases dependent upon impaired or perverted nutrition it has proved disappointing, although it was just in this class of case that great things were formerly expected from the study of its physiological effects.

In gout, rheumatism, diabetes, and obesity it has been extensively tried, but hitherto the results obtained have hardly justified anticipations. In diabetes, for instance, although numerous cases have been published in which a diminution of sugar has been observed, its complete disappearance is very rarely noted, and the patients generally remain diabetic throughout. Decrease of the daily sugar in diabetes can be produced by various forms of electrical application, notably by the electric bath with sinusoidal current, but the cure of diabetes is quite another matter, and, so far, it cannot be accomplished with any certainty by electrical methods of treatment, although a few apparently successful cases have been recorded.

In gout it appears that the high frequency treatment may

precipitate an acute attack. In acute rheumatism it is considered by certain experimenters to be contra-indicated. In chronic rheumatism good results have been obtained, but only after numerous applications. Apostoli and Laquerrèire have stated that 25 or 30 applications at least are necessary, while 200 or 300 may be required.

In diseases of the nervous system high frequency currents have been extensively tried, and several cases of muscular atrophy have been recorded in which the treatment seems to have led to a decided improvement in the condition of the affected muscles, both as to their bulk, their power, and their electrical reactions. In neuralgic pains and in neuritic affections with pain, as, for example, in sciatica, some encouraging results have been obtained. In other affections of the nervous system high frequency has not yet accomplished much.

140. **Tuberculosis.**—High frequency applications have been strongly advocated in the treatment of pulmonary phthisis by Mr. Chisholm Williams.* His opinions were based upon the results obtained in forty-three cases; and he states that in general there was a gain in weight with increase of appetite and digestive power. Temperature was raised for a time at the commencement of treatment and the numbers of tubercle bacilli in the sputum were also increased. After a time the temperature returned to normal, and the bacilli decreased in numbers while the patient's body weight and general condition became greatly improved. In 1903 Mr. Williams was able to announce that 39 of the 43 patients were alive, and one had been recently exhibited at a medical society as a case of arrested phthisis.†

In this connection it is interesting to note an extended series of experiments on guinea-pigs conducted by Drs. Lagriffoul and Denoyés, and recorded by Dr. Denoyés in his book. He there insists that the treated animals were less affected by the inoculations than those left untreated. Otherwise the results were not strikingly successful, but it must be borne in mind that the generalised tuberculosis of guinea-pigs differs in many important particulars from the course of chronic pulmonary phthisis which is observed in human beings. In the former tubercle behaves as an acute general infection, but in the latter the tubercular condition is more of the nature of a local disease spreading

* *Brit. Med. Jour.*, Oct. 12, 1901, Oct. 24, 1903.

† *Medical Electrology and Radiology*, vol. v., p. 40.

slowly and leading indirectly, rather than directly, to the destruction of vital parts.

Oudin, Doumer, Rivière and others have also reported favourably upon the effect of high frequency in pulmonary tuberculosis and have published cases. Further investigations into the question are certainly desirable.

141. **Diseases of the skin.**—The local application of high frequency discharges to cutaneous disorders was introduced by Oudin in 1894. His work has shown that this is a field in which high frequency is of great value. The applications are sometimes made with an ordinary wire brush electrode, but more usually with one of the glass electrodes figured above, or with the effluve from points held just beyond sparking distance.

The morbid conditions of the skin in which success has been most commonly obtained with high frequency treatment are pruritus, lichen circumscriptus, psoriasis, eczema, acne, sycosis, and lupus. The action seems to be one of stimulation or counter-irritation, and perhaps the generation of heat, and the production of ozone and of oxides of nitrogen at the actual skin surface, may play a not unimportant part in bringing about a favourable result.

This action of high frequency discharges in cutaneous disorders was not anticipated at the commencement; but now that it has been discovered by experiment, one can readily see that a favourable action might reasonably have been expected in such cases, because of the directness with which the powerful electric discharges can be brought to bear upon the affected parts. The effect of the brush discharge of a static machine in promoting the healing of ulcers has long been known to those who have studied the subject, and it is probable that the action of the high frequency apparatus, in this respect, is closely comparable to that of the static machine.

142. **Lupus.**—There is no doubt that high frequency applications have an effect upon lupus, which is similar to the effect of X rays or of the Finsen lamp. The action of the static breeze upon lupus, mentioned in the preceding chapter, must be borne in mind in this connection. Several writers have published cases which appear quite satisfactory. Chisholm Williams has reported that twenty applications of five minutes each, extended over ten weeks, suffice to clear up any non-ulcerated small patch

of lupus. The effluve, the high vacuum glass electrode emitting X rays, or an ordinary glass electrode may be used.

143. **Piles and rectal fissure.**—A group of conditions for which high frequency has been found useful, is that of piles, rectal fissure, and pruritus ani. These are treated by means of a special electrode (fig. 103), consisting of a stem carrying a cone-shaped extremity of bare metal. Doumer has reported 26 cases of piles which were all more or less successfully treated. He finds that the benefit is most marked in recent and acute cases, and least so when there were considerable structural changes in the parts.

FIG. 103.—Rectal electrode.

144. **Malignant disease.**—Dr. Allan* of Chislehurst published, in 1901, some cases of malignant disease treated successfully by high frequency applications. Chisholm Williams† also has put on record the notes of two cases of epithelioma in which favourable results followed high frequency applications. In some of these, but not in all, the electrode used was a vacuum tube emitting X rays.

145. **New source of high frequency currents.**—In § 98 reference was made to Duddell's "singing arc" and its possible use as a means of obtaining high-frequency currents. Professor Wertheim Salomonson of Amsterdam has investigated the oscillatory currents of high frequency which are produced when the carbons of a direct current arc are connected in shunt to a condenser. By interposing the primary of an induction coil, without iron, in series with the condenser, he is able to obtain from its secondary coil a simple sinusoidal current of high frequency, and states that he has obtained frequencies higher than 300,000 per second. These differ in one important particular from the discharges of an ordinary high frequency apparatus, inasmuch as the oscillations are continuously maintained, whereas with the high frequency instruments described in

* The later histories of these cases is not yet reported.

† *Medical Electrology and Radiology*, vol. v., p. 43.

this chapter the individual groups of oscillations are of very short duration, they rapidly die out when formed, and are renewed again after intervals which are relatively long in comparison with the duration of the oscillations.

CHAPTER VIII.

The Electric Bath.

The monopolar bath. Accessory apparatus. The resistance of the bath. The mode of application. The use of the electric light mains. The arm-bath. The dipolar bath. Dr. Schnee's four-cell bath.

146. **Advantages of the electric bath.**—The electric bath is used in the treatment of many morbid conditions because it provides a convenient and agreeable way of applying general electrisation to the whole system, a method of treatment of great value whenever general stimulating and tonic effects are required.

General electrisation has a very powerful trophic influence upon the body, and is most useful in the treatment of many morbid states, such as anæmia and chlorosis, rickets, rheumatism, rheumatoid arthritis, gout, sciatica and lumbago, and generally in diseases due to defective nutrition; in neurasthenic states, also in general neuritis following diphtheria, influenza and other specific fevers, and to promote recovery after debilitating illnesses.

General electrisation, as carried out by means of an electric bath, is agreeable to the patient, and far more efficacious than the older processes of "general faradisation" or of "central galvanisation" referred to in a later chapter.

The electric bath is not only the best method of applying general electrisation, but it also has great advantages for local treatment when the area to be treated is an extensive one, as for instance in sciatica, in hemiplegia, or in infantile paralysis, where the whole of one or more limbs may require electrical treatment.

The advantages of using a bath of water as a means of conveying electricity to a patient are as follows:—

First, the water provides the best of conducting media because it adapts itself so completely to the surfaces of the body. Secondly, by moistening the skin uniformly and thoroughly, it

lowers its resistance and favours the comfortable passage of the current through the skin.

Thirdly, all parts of the body are brought under treatment together, and this simplifies matters both when the body as a whole is to be treated, or when there are a number of separate areas all requiring attention.

Fourthly, because the warm water serves to keep the patient warm and comfortable during the time of the application. We may also include the stimulating action of the hot water upon the skin, for this is an additional therapeutic means that may often be of service in the cases which are being treated by electricity. For instance, lead poisoning, which is greatly benefited by electrical treatment, is also influenced favourably by hot baths, so much so that a course of the thermal waters of Bath was at one time a recognised treatment for cases of lead poisoning. In infantile paralysis a hot bath given daily is an useful therapeutic application and one which can be combined very advantageously with the electrical treatment.

In many skin diseases electric baths act very efficiently, and the use of water or dilute saline solutions as the electrode is especially happy in such conditions, in which the rubbing of the sore surface with leather-covered electrodes is quite unsuitable.

An interesting point which has been often observed with electric baths, is that acne of the back disappears during a course of bath treatment.

147. **The ordinary or dipolar bath.**—The bath itself should be made of porcelain or glazed earthenware, or it may be made of wood. The former is the best, as it is easily kept clean and has a good appearance.

A bath five feet six inches in length is long enough for the great majority of cases. For female patients, a five foot bath is sufficient as a rule.

The water in the bath should be agreeably warm, averaging 99° F., but it may be slightly warmer or cooler to suit the wishes of the patient. It is noteworthy that a difference of one or two degrees makes a great difference in the sensations of warmth felt by the patient at these temperatures. On this account a bath thermometer should always be used to ascertain and regulate the temperature. The bath should be so filled with water that when the patient lies in it the whole body and the shoulders may be covered.

Two electrodes consisting of metal plates are fixed at the head and foot of the bath, and they should always be kept clean and bright. These metal plates are provided with binding screws to which the battery wires are attached (fig. 104). Copper has a bright appearance, but zinc may also be used. It is of no use to have the electrodes plated with nickel or silver, as is sometimes done for appearance sake, for the plating quickly leaves the positive pole. The electrode placed at the

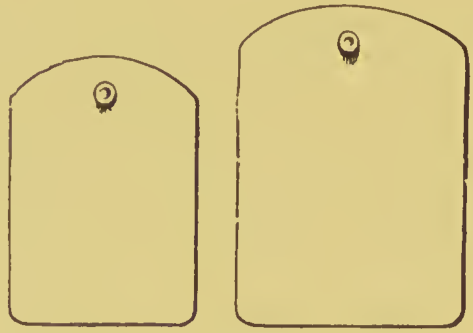


Fig. 104.—Electrodes for the bath.

head of the bath is usually the larger, and may measure eighteen inches by twelve, that at the lower end of the bath being eleven inches by nine. In order to localise the current more or less in any part, a movable paddle (fig. 105), two or three inches square, connected by a long flexible wire to the foot plate may be used. It may either supplement the foot plate or replace it. The water in the bath should be deep enough to cover the plates.

Fig. 105.—Paddle electrode.

The shoulders and back of the patient are kept from touching the plate at the head of the bath by a rest made of wood, something like a picture frame having pieces of webbing stretching across (fig. 106). The light wicker fire screens which are made to fit on to the backs of chairs are also very convenient and comfortable for the purpose. Though rough to the hand when new they soon become softer and do not hurt or scratch the back; with female patients the bathing dress gives additional protection.

The feet may be allowed to touch the electrode at their end of the bath, because the epidermis on the soles is thick enough to take care of itself. If a patient is timid, the feet need not be placed in actual contact with the metal, but they should be kept in close proximity to it. The arms must be extended if they are to share in the treatment, and folded if the current through them is to be kept small. A part only of the total current in circuit traverses the body, the remainder passing through the water in which it is immersed. The water in the bath offers a broad conducting medium with a large transverse sectional area, several times larger than the patient, and therefore a considerable part of the current traverses the water and is altogether lost to the patient.

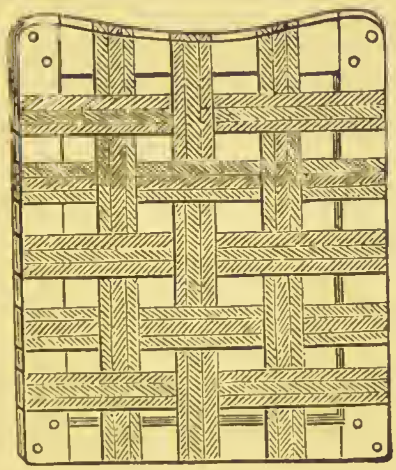


FIG. 106.—Back rest.

An electric bath was installed at St. Bartholomew's by the late Dr. Steavenson in 1882, and was for many years the only electric bath at a London hospital. Recently, one or two other hospitals have recognised their advantages and have taken them into use. The bath method of applying electricity has further been extended by the introduction of arm-baths and foot-baths, as well as the large general bath; so that there are now at St. Bartholomew's Hospital five of these small baths in regular use, to the great advantage of many patients, and with the effect of greatly simplifying the process of treatment; better results are now obtained in many conditions of disease by bath methods than was formerly the case.

148. **The resistance of the bath.**—The resistance in an electric bath will vary with its length, with the depth to which it is filled, and with the temperature of the water.

Dr. Hedley* has contributed largely to our knowledge of the physics of the electric bath, and his book should be studied by all those who are interested in the subject.

A porcelain bath five feet six inches long has a resistance of about 110 ohms, when filled with water at 100° Fahr. to a depth of fifteen or sixteen inches.

A question of interest with the electric bath is the following:—How much of the total current passes through the patient, and how much is conveyed by the water? The answer will depend upon the dimensions of the the bath, and also on the quantity of water in the bath; the problem is best attacked by regarding the condition as one of a divided or branched circuit; the water being one, and the patient the other of two conductors; the proportion of current traversing each will depend upon their relative resistances. But the thicker parts (trunk) of the patient will convey more than the average, and the thinner parts (limbs) less, so that one cannot say that the patient carries such and such a fraction of the total.

M. Meylan† has contributed some experimental data upon this question. He measured the resistance of a bath first with a patient immersed; secondly, with the patient removed, the water as before; and thirdly, with the patient removed, but with water added to bring the level up to that which it had when the patient was in it.

The measurements were as follows:—

A. Water and patient ...	... 136	ohms resistance.
B. Water only	... 151	,, ,,
C. Water, with water added ...	130	,, ,,

By calculating out these figures he arrives at 1360 ohms as the patient's resistance, and 1033 ohms as that of the equivalent bulk of water added in experiment C. The resistance of the patient was rather greater than that of his own volume of water spread out in a layer over the area of the bath. The cubic measurement of an average sized man is three cubic feet, or about eighteen and a half gallons.

* "Hydro-Electric Methods in Medicine." London, H. K. Lewis, 1896, Second Edition.

† *Revue internationale d'électricité*, vol. v., p. 113 (Nov. 1894).

If we compare the resistance of the water only, 151 ohms, with that of the patient, 1360 ohms, we find that under the conditions of the particular bath, the patient's body would be conveying about one-tenth of the current.

As the current which traverses the water does not affect the patient, and therefore may be considered as wasted, it follows that for economy of current the amount of water used in the bath should be no more than enough to cover the patient comfortably. On the other hand a large volume of water retains its heat better for the time required for the bath, and should be preferred on that account, the waste of current being a matter of minor importance.

If salt or acid is added to the bath, the water becomes a better conductor than before, and the patient's share of the total current passing will be reduced. It is therefore improper to make such additions to the water. The duration of a bath should be from ten to fifteen minutes. The first five or six baths may be given on consecutive days, and then every other day until the end of the course, or they may be given on alternate days throughout. A course may consist of from twelve to twenty baths. A patient may have more if he is continuing to progress; but often after a course is over, the patient's condition will continue to show improvement after the baths have been left off.

149. **Choice of current.**—The direct current, the interrupted current of the induction coil, or the sinusoidal current of an alternate current dynamo may be used in the bath. "Galvano-faradisation," a combination of induction coil currents with a direct current, has also been recommended. Three phase currents (§ 107) may probably come into use with the electric bath, and have been recommended for this purpose.

Of these the first is specially indicated for the treatment of painful conditions where the coil current or the sinusoidal current is not well borne. Thus the direct current is useful in the earlier stages of general neuritis, in neuralgias, and in acute sciatica. Again, where an effect on joints or other deep seated parts is hoped for, as in rheumatoid arthritis, gout, and rheumatism, the galvanic bath may be preferred. It has also been recommended in degenerative states of the spinal cord where irritative symptoms are present, as for instance, in chronic myelitis, progressive muscular atrophy, in lateral sclerosis, and

in tabes. A few cases have been published where these conditions have seemed to be benefited in this way. The vast majority, however, have received no benefit, and it is still quite uncertain whether anything can be hoped for in the future from the electrical treatment of these progressive spinal cord diseases. Hitherto, it must be confessed, we have not discovered how to apply it for their cure, so that one is almost tempted to believe that the few cases which have been recorded as successful may have been misinterpreted.

It must be borne in mind that the bath plays a quite secondary part in electrical applications, and that it is valuable rather as a convenient mode of bringing the current to the patient than as having any essential therapeutic qualities of prime value. If in the future an electrical method of influencing these degenerative spinal diseases should be discovered it would then be time enough to consider whether the applications could be advantageously carried out in a bath or not. In the electrical treatment of these diseases there is most promise of future possible success with the direct current applied to the region of the spine, and for this the use of the bath does not seem specially indicated, because the spine can be easily reached and treated without it.

The induction coil bath and the sinusoidal current bath are indicated where simple nutritive effects are required. Debility of all kinds, chlorosis and other forms of simple anæmia, peripheral paralysis and infantile paralysis (except where recent or acute), the later stages of transverse myelitis; lumbago and sciatica, except when acute, and rheumatism and rheumatoid arthritis are all greatly relieved by the electric bath with coil or sinusoidal current. The physiological effects of both forms are similar; the differences between them are chiefly in the greater smoothness of the latter and the larger currents which can be borne with it. It is a less sharp stimulus to nerves and muscles. In most cases the sinusoidal current of a dynamo is to be preferred if it can be obtained, but in its absence the current of an induction coil may be used in its place.

150. **The induction coil bath.**—For a coil bath a coil with a secondary of few turns is best, because the magnitude of current is relatively large, and the volts needed are small (§ 64). In those coils which are tapped in such a way that either a part or the whole of the total turns can be used, it is

generally better to use the part than the whole coil. Regulation can best be carried out with a coil of sledge pattern (fig. 21). The paddle electrode, fig. 105, should be used. If it is brought near to the abdomen brisk contractions can be set up in the abdominal muscles.

For stimulating the muscles of the trunk, and especially the abdominal muscles, the jerky impulses of the induction coil act best; and the coil is to be preferred for treating cases of constipation, or weakness of the muscles of the abdominal walls.

151. **The use of direct current from the mains.**—With proper precautions the electric lighting mains may be used for supplying direct current for the electric bath.

A practical point of great importance in such proceedings is the possibility of leakage to earth from the conductors of the current supply systems. It has been proposed to guard against this risk by the insulation of the bath from earth connections, but the complete insulation of a bath which is even indirectly in relation with water supply-pipes and waste-pipes is almost impossible. It is troublesome, and is very likely to fail at an inopportune moment. On a circuit of 100 volts this is bad enough, but with 200 volts or more between one conductor and earth a failure of the insulation might be very serious. The tendency towards 200 volts systems of supply and the use of the three wire and five wire systems increase the difficulty of dealing with the leakage to earth by any insulation method.

In my opinion no method which depends for its safety upon the maintenance of the insulation from earth of a bath containing water is good enough to risk, and it is therefore best not to attempt to insulate the bath, but on the contrary to have it thoroughly well earthed. Its metallic water-pipe connections generally suffice, but to make sure the cold-water pipe can be joined by a soldered-on wire to the waste-pipe. The bath may then be used with safety, the leakage to earth being allowed for and the voltage regulated by resistances in series with the bath, and fixed to both conducting wires at both ends of the bath, because the patient would be insufficiently protected from discharges to earth of serious magnitude by a resistance which was placed on only one of the two conductors of the bath. The method of a shunt circuit to provide a slope of potential which can be tapped as desired (§ 89) may be used, provided that the safety lamp (B, fig. 62) be chosen of a proper resist-

ance, and be inserted in duplicate so as to protect both ends of the bath.

With direct current mains of 200 volts or upwards, much security will be afforded by the use of a battery of accumulators for the bath. These can very easily be charged from the mains when required, and the use of an interlocking switch will compel the cutting off of the mains when the bath circuit is connected.

152. **The sinusoidal current bath.**—This is the form of bath which has been most studied and used in recent years. Its employment has been made easy in many places by the systems of alternate current electric light supply which provide a suitable sinusoidal current (§ 55), and it has added greatly to the usefulness of the electric bath as a therapeutic agent. It is the kind of electric bath most useful for general purposes. At St. Bartholomew's Hospital it has been very largely made use of for many years.

D'Arsonval showed that the effects of electrical currents in increasing metabolism must be separated into two sections. In part the metabolic action is due to the muscular contractions provoked by the currents and is a secondary effect, but he also has insisted that with some types of electrical current there may be decided increase of metabolism, even when no actual contractions are produced in the muscles. The sinusoidal current has been especially indicated by him as possessing this property and of stimulating metabolism, independently of any effect in causing muscular contraction. Gautier and Larat* were among the first to make practical application of these physiological researches of Prof. D'Arsonval's, and to point out the convenience of an electric bath for the employment of sinusoidal currents in practice. In their papers they have pointed out that the general application of sinusoidal currents through the medium of the bath has a beneficial action in many forms of defective nutrition, that they cause a reduction in the sugar excretion of diabetics, a fact which has often been verified since, and that old eczemas have also been favourably influenced by these currents.

In the absence of alternating current mains a small dynamo can be used to generate the current, and may be driven by a water motor, or by a continuous current motor worked by a battery of accumulators or by the direct current mains if they are available (§ 92). The instrument figured on p. 131 is well

* *Revue internat. d'électrothérapie*, 1894 and 1895.

suited for this purpose. There may be leakage to earth and so to the bath of the direct current driving the machine, and to guard against this and at the same time to regulate the strength a small adjustable transformer (§ 99) is the best instrument, and the same form of appliance is wanted with the alternating electric light mains. A proper voltage for the bath is between four and eight with an average of six. If a milliamperemeter is kept in circuit a higher voltage may be required to overcome the resistance offered by that instrument.

153. **The mode of administration.**—The patient after entering the bath should be allowed a minute or so to recover from the reaction produced by the warm water before the current is turned on. The current should be increased slowly and cautiously, and the galvanometer watched, and at the termination of the bath the current must be reduced as slowly. The direct current for a bath may be very gradually raised until the galvanometer registers 100, 150, or even 200 milliampères, but it is best for the first few baths to use a current not exceeding 100 milliampères. A battery of large Leclanché cells or accumulator cells may be used with a switchboard having a double or single collector (§ 77) and a commutator (§ 78); a galvanometer graduated to read up to 200 milliampères must be included in the circuit. The direction of flow should generally be from the head to the feet, the anode being at the upper end of the bath, and the kathode at its foot. There is no certain knowledge of the effect of the direction of flow in treatment by the constant current bath, but the direction here given represents the views of the late Dr. Steavenson, in the treatment of electric bath cases. With the sinusoidal current 30 or 40 milliampères are generally sufficient. With induction coil currents the strength should not be so great as to make the patient's muscles rigid. A metronome or other rhythmic interruptor (§ 82), is a very useful adjunct; when one is employed the currents may generally be reduced with advantage. A medical man should always be present to regulate, increase, or diminish the strength of the current. The patient can wear an ordinary bathing costume. With female patients the presence of a nurse or a maid is necessary, but the medical man should also remain in the bath-room while the current is flowing. As the current is slowly augmented the first sensation experienced by the patient is usually a slight pricking or tingling at the ankles or

at the knees. A metallic taste may be perceived as the current becomes stronger. Should the patient's head feel full or throbbing during the administration of the bath a cold wet towel may be placed on the top of the head. And if any faintness is caused, the current must be reduced. An electric bath must not be taken too soon after a full meal. After the bath the skin of the back near to the upper electrode will be found of a bright red hue, this will gradually pass off in an hour or two. After dressing, the patient should rest for ten or fifteen minutes before going out into the open air, and should walk home if able to do so. After an electric bath there appears to be no particular tendency to catch cold and the patient generally feels exhilarated and better. Should there be any sign of languor or depression after a bath, currents of small magnitude should be employed.

It is usual for patients to feel a little inclined to sleep some hours after a bath, and it is as well to tell them of this beforehand or they may take it as an unfavourable sign.

After the bath it is best that the patient shall dress slowly in order to allow the activity of the circulation in the skin to diminish during the process of dressing. If this is not done there is a risk that the skin will perspire sensibly and that the patient will feel damp and uncomfortable, and will run the risk of taking a chill. With due care there is very little danger of cold after an electric bath. Among the very numerous patients who come to the hospital for electric baths throughout the year the taking of a cold afterwards is practically unknown.

The duration of the bath should be for ten or fifteen minutes, and they may be given on alternate days. Twelve or more baths are needed to produce a good result in most cases, and may be taken to constitute "a course." But in many chronic states more than this number will be wanted.

In all electric bath treatment the utmost care must be taken with the conducting circuits and the regulating apparatus. The least neglect of the connections, both at binding screws and especially at the sliding connections which have to do with regulating and varying the strength of the current, is likely to lead to annoyance and the loss of patients. The patient in the water is so completely helpless that he may justly be alarmed at the occurrence of anything unexpected in the way of sudden changes in the flow of current, and he may consider it to be

dangerous to come for any more treatment if he has once received a disagreeable shock. A loose wire end in a binding-screw or a conductor broken inside its coverings of insulation may be enough to give trouble in this way. Servants can seldom be trusted to see to the wire connections of an electric bath. It is a wise precaution to make a rule of always making trial of the entire bath circuit at the last moment before the patient steps into the water. It is never safe to omit this precaution, and it is too late to think of it when the patient is already in the bath.

154. **Local baths. The arm-bath.**—A bath of water may often be used with advantage as a means of applying electricity locally, especially in the form of a foot-bath or an arm-bath.

The arm-bath is specially suited for cases of paralysis of the muscles of the forearms and hands, as for example in the extensor paralysis of lead poisoning, and in paralysis from various injuries to the nerves of the forearm ; also in rheumatic and gouty affections and rheumatoid arthritis affecting the elbows, the wrist or the finger joints, and in Raynaud's disease, or in chilblains affecting the hands, while the foot-bath is valuable for applications to the feet in the last-mentioned disorders. A consideration of this list will show how often the arm-bath can be of service, particularly in general practice or in the electrical department of a hospital. Moreover the use of the arm-bath greatly simplifies the process of applying electricity to a patient, by doing away with the tedious process of rubbing the electrodes over the affected parts. For these reasons the arm-bath is a valuable method of applying electricity, and one which deserves general adoption by the medical profession. The constant current, the coil current, or the sinusoidal current may be applied in the arm-bath with equal advantage.

An arm bath can easily be arranged in any non-conducting vessel of suitable size. Oblong stoneware troughs are made for kitchen use which are exactly suited to take the hands and forearms, and Mr. Miller (93 Hatton Garden, E.C.) can supply them with electrodes already fitted. For a direct current arm-bath nine, ten, or twelve Leclanché cells are enough and will give a current ranging from 25 to 40 milliampères.

A good form of electrode is one made of sheet metal cut out in one piece in the shape of a tennis bat, with the handle part bent into a hook, which serves to hang the electrode from the

end of the trough. It is fitted with a binding screw at the extremity. When the arm is immersed in the warm water of the bath the current passes in part by the water, and in part through the limb, just in the same way as it does in the full length dipolar bath described above. When the treatment is to be applied to both forearms, both can be immersed in the one trough. When the legs are to be treated there may be two troughs, with one electrode in each. One foot is to be immersed in each trough, and the path of the current is then through the legs and thighs, and each of the troughs or tubs become one of a pair of monopolar baths.

155. **The monopolar bath.**—When an electric bath is so arranged that one electrode only is immersed, and the whole current passes from it to the patient, it has been called a monopolar bath to distinguish it from the ordinary or dipolar bath. A monopolar arrangement for use in a full length bath has been employed, but has now been given up in favour of monopolar arrangements of arm- or foot-baths. With the full length bath the patient grasped a metal conductor, generally a bar or handle covered with flannel, which was fixed above the water level. The current passed from that conductor to the hands and so along the wrists and arms to the body and to the water of the bath to reach the other conductor which was submerged in the bath.

An objection to this arrangement was that the current was too strong at the wrists or too weak elsewhere, although the scheme had certain advantages in cases of wrist-drop from lead poisoning and in cases of arthritis of the wrist joints.

By using two vessels of water and immersing one extremity in each, with one electrode in each, the arrangement becomes one of two monopolar baths; it is a method which has been particularly used in connection with electro-chemical medication. The classic instance of this use of an electric bath is to be found in a communication of Mr. Edison's, read by Dr. Bayles of Orange, N.J., at the International Congress of Electricians held in Berlin in 1890.* Edison caused patients to dip one hand into a solution of lithium chloride of the strength of five per cent., and the other hand in a solution of

* For an account of Edison's experiments, see Dr. Peterson's article on "Cataphoresis" in the "International System of Electrotherapeutics," by Bigelow and Massey. London, 1902.

common salt. After the passage of a current from arm to arm in this way lithium could be detected in the urine, and gouty symptoms were ameliorated after a prolonged course of these baths. Other writers have published some cases in which they have obtained good results in this way.

156. **The four-cell bath of Dr. Schnee.**—This is a monopolar bath carried to a high degree of perfection. It consists of a special chair, provided with four glazed earthenware baths, one for each limb of the patient who sits in the chair (fig. 107). The baths are connected by wires to the source of current, and the current can be made to traverse the patient's limbs in any required manner. Thus in cases of paraplegia the two foot-

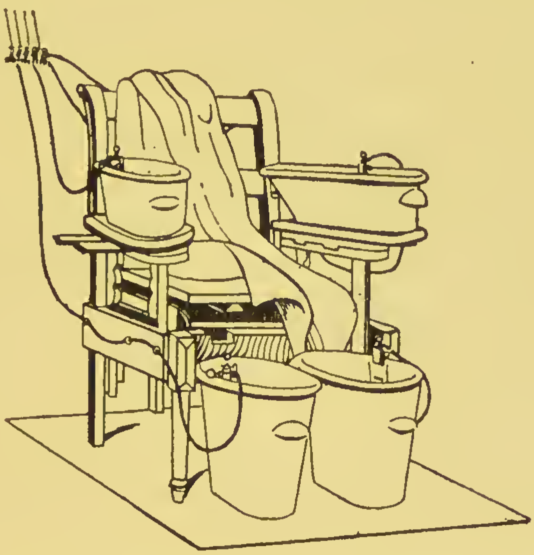


FIG. 107.—The four-cell bath of Dr. Schnee.

baths would be used, in hemiplegia one arm-bath and one foot-bath, and so on. A very convenient switchboard forms part of Dr. Schnee's apparatus, and it is fitted with voltmeter and ammeter, with an adjustable resistance for purposes of regulation and with a motor-generator by means of which direct current, sinusoidal current, or interrupted current can be provided for the baths. There is also a simple plug arrangement with switches, so that the polarity of any of the baths can be altered at will.

One of these instruments has been in use at St. Bartholomew's Hospital for several years, and has proved to be a most valuable appliance for the electrical treatment of many kinds of cases.

From 20 to 25 milliampères are comfortably borne between arm and arm, and the electromotive force required for this current is about 25 volts. With the lower limbs slightly larger currents can be used.

157. **The electric douche bath.**—A douche arrangement so connected to the battery as to convey an electric current with the stream of water is an useful adjunct to an electric bath.

It would be easy to contrive a circuit composed of bath tub, patient, and douche pipe, so that a current would flow when the douche was turned upon the body of the patient. The idea is said by Erb to have been first originated by Trautwein in 1884, (*Zeitschrift f. klin. med.*, viii., p. 279, 1884).

Dr. Hedley recommends the administration of electric currents by means of the douche as a valuable therapeutic procedure, and points out its adaptability to some forms of internal application.

In the *Revue internationale d'électrothérapie*, for June, 1894, Dr. Guyénot, of Aix les Bains, has described a method of applying electricity by means of douches. The current is led to and from the patient by two streams of water, the conductors being connected to the metal nozzles through which the water flows, and he insists upon the ease with which the jets of water can be made to carry the current to the whole surface of the body, or to any part of it, so as to give the effect of a general or of a localised electrisation. The article gives careful working details of the modes of applying either the battery current or the induction coil current, and the account is well worthy of attention.

Of late years electrical applications have come into very general use in spas and health resorts, not only abroad but also in this country, and this speaks volumes for the superior advantages of electricity over hydrotherapy pure and simple. Electro-therapeutics also find a more favourable public at such places than they do in large and busy towns, for patients who cannot spare the time for a regular course of treatment when at home are able and willing to do so when staying at a health resort, and detached from their daily business.

158. **The elimination of metals from the body.**—The removal of metallic poisons from the body by electrolysis in the electric bath has not had much attention since the time of Poey, who made a communication on the subject to the French

Academy of Sciences in 1855.* In this it is stated that mercury in metallic globules had been deposited upon the negative pole of the bath in which a person was placed after a course of mercurial inunctions. It is most likely that the mercury, which seems to have been properly identified by chemical tests, must have come from the surface of the skin of the patient.

Althaus refers to a case of argyrism in which a large number of baths were given with the object of removing the silver deposited in the patient's skin. The treatment was quite unsuccessful.

In one instance which came under my own observation a patient with lead palsy was treated with a direct current bath, and the electrodes of the bath were examined to see whether any electro-deposition of the metal had been brought about in the course of the bath. A grey deposit, which gave the proper chemical reactions of lead, was found upon the negative electrode; but it was not possible to be certain that the lead had come from the patient's tissues, for it might have been derived from lead compounds upon the surface of his body.

The idea of eliminating metals from the system by means of electric baths appears to have been abandoned.

* Becquerel, "Traité des applications d'électricité à la thérapeutique." Paris, 1857.

CHAPTER IX.

Physiology.

The resistance of the body. Diffusion of current in the body. Electrolysis. The capacity of the body. The action of electrical currents on living tissues. The motor nerves and muscles. Unstriped muscle. Sensory nerves. Refreshing action. Trophic effects. Electrical osmosis. Lethal effects. Magnetism.

159. **The resistance of the body.**—The body is a conductor exactly in the same way as saline solutions or moist sponges are conductors, that is to say, it is an electrolyte, and the tissues between the electrodes during the passage of a current are in exactly the condition of the liquids in an electrolytic cell, consequently the passage of the current causes the accumulation at the positive electrode of acids, chiefly hydrochloric, from the abundance of sodium chloride in the juices of the body, and of bases, chiefly soda from the same reason, at the negative electrode. The region between the poles shows no evidences of either free acid or free alkali, and yet we feel sure that exchanges must be taking place all through the chains of molecules between anode and kathode. Moreover, it is not reasonable to assume that the changes only occur in the fluids of the intercellular spaces, for they must also go on in the whole of the cell substance which is traversed by the current.

The resistance of a patient's body, as observed clinically, is almost entirely a resistance at the contact of the electrodes with the skin, it can be varied in many ways, and it does vary from day to day in the same patient. As for the resistance of the tissues beneath the skin, it is a matter of a few hundred ohms. Careful measurements of the resistance of patients, and statements as to the degree of resistance in different morbid states cannot therefore be of much value or importance. Low resistances have been observed in Graves' disease, in which the skin is usually moist, and high resistances in hysteria, in melancholia, and in paralysed parts.

The medical practitioner is concerned with the resistance of

the body mainly as it affects the question of treatment, and the number of cells required to drive the proper current through the patient. Under conditions of medical practice, and using moistened electrodes, the resistance of the body, when the skin is well wetted with warm water, ranges between one and three thousand ohms, that is to say an electromotive force of twelve volts (eight Leclanché cells) will pass a current of from four to twelve milliampères. If one electrode is placed on the palm of the hand the resistance will be at least double. Difficulties in the testing of the reactions of muscle sometimes occur from not remembering this point, for an electromotive force with which contractions are easily set up in the muscles of the forearm and of the back of the hand, may produce no effect at all when the testing electrode is transferred to the palm. A glance at the galvanometer will, however, show the reason why, by indicating a smaller current and a greatly increased resistance.

An excessive resistance is sometimes offered by the dry skin (and accumulated epidermal cells) of patients who have been long confined in bed, especially when there has been little or no perspiration for some time, and this occasionally presents a considerable obstacle to the electrical examination of the muscles of such patients, and unless care is taken it is apt to mislead.

Different observers have given the most widely divergent figures for the body resistance, the range being from one thousand to two hundred thousand ohms, according to the nature of the contacts used in the experiments. The human epidermis, when dry, offers a very high resistance indeed, especially if it be at all thick and horny like that of the palms of the hands and the soles of the feet. When moistened and permeated with water or salt solution, its resistance becomes much less; the internal tissues of the body have a comparatively low resistance, and the only value of most of the experimental determinations of resistance is that they show how enormously the resistance of the skin may vary. The resistance offered by any patient depends upon the following points:—*First*, the state of the skin, whether thick or thin, dry or moist, cold or warm. *Second*, the area of the electrodes and the efficiency with which they are brought into contact with the surface of the body. *Third*, the electromotive force of the battery used in the test; and *fourth*, the duration of the test. With low electromotive forces, one volt for instance, the resistance is much greater than

with higher voltages, and polarisation becoming set up at the surface of the electrodes tends to make the apparent resistance even greater than it really is. With higher voltages the passage of the current produces at first an increased vascularity of the skin under the electrodes with diminution of the resistance, and if the current be continued, so as to cause the skin to be gradually destroyed, the resistance is further diminished.

Leduc, interpreting the phenomena of skin resistance in the light of the laws of electrolysis, points out that the skin behaves as an electrolyte poor in ions. It was shown in § 25 that a solution conducts well or badly in proportion to the number of free ions which exist in it. During the passage of a current there is a movement of ions from the tissues of the body and from the electrodes into the skin, and the resistance therefore falls, at first rapidly, but afterwards more slowly, until it reaches a steady value. The final values differ for different ions; the simpler ions, as for example, those of chlorine, or of sodium, showing a greater reduction in resistance than the more complex ions of calcium, of cocaine, or of cacodylic acid. Salt solution is better than plain water for moistening electrodes, because it provides abundance of free ions to convey the current.

Dr. Stone,* in a careful study of the resistance of the human body, arrived at the figure of one thousand ohms as the average resistance from foot to hand, and from foot to foot, when the contacts were made through large vessels of salt water into which the extremities were plunged. In this way he thought he had succeeded in eliminating the resistance of the skin, and considered that the figures obtained indicated the resistance of the deeper tissues only.

Professor G. Weiss† measuring the resistances from hand to hand with contacts made through bowls of salt water, found the average resistance in sixteen men to be a little over thirteen hundred ohms, and in seven women fifteen hundred ohms, the reason why the latter showed a higher figure is not very clear, particularly as the skin of women is generally believed to be more thin and delicate than that of men. It may have been due to the smaller surface of the hands of the women, or perhaps to a lesser number of sweat glands and hair follicles; the difference, however, is not great, and would probably be less apparent if a larger number of cases had been measured.

* Lumleian Lectures, 1886. † *Arch. d'électricité médicale*, 1893.

When the electrodes are applied to mucous surfaces, or are in the form of needles thrust through the skin, the resistances are much lower. With needles of both poles inserted into a nævus, the resistance may be as low as a hundred ohms, and it is said that with needles in an aneurysmal sac readings as low as ten ohms have been recorded. By a method which eliminates the skin resistance, Weiss has found the resistance from shoulder to shoulder to be no more than forty ohms, and from elbow to elbow two hundred and fifty ohms.

In some measurements made in the post-mortem room at St. Bartholomew's Hospital, the resistance of the tissues, not including the skin, was found to range between two hundred and four hundred ohms.

During the treatment of a patient the resistance of his body may be calculated by Ohm's law from the galvanometer reading and the electromotive force of the cells, if that be known. For example, with twelve Leclanché cells in good order the electromotive force will be eighteen volts, and if the current through the patient be four milliampères the resistance may be taken as follows:—$R = \frac{E}{C}$, $E = 18$ volts, $C = \cdot 004$ ampère, therefore $R = \frac{18}{\cdot 004}$ or 4500 ohms. In this way an estimate quite close enough for most cases can readily be formed. When exact measurements are required a Wheatstone's bridge arrangement, with a battery current and a galvanometer, or with an alternating current and a telephone (Kohlrausch's method), must be employed (Ayrton's "Practical Electricity," or Kempe's "Handbook of Electrical Testing"). The latter method has been preferred, because it eliminates the difficulty of polarisation, but this has probably been over estimated, and the telephone method introduces other difficulties of its own. Prof. Weiss' paper* indicates a method of overcoming the difficulties of polarisation when the battery and galvanometer method is used.

During the progress of treatment the electromotive force in circuit which is employed at the commencement must be reduced gradually to compensate for the fall in resistance which

* *Loc. cit.* See also Bordier, *Précis d'électrothérapie*; Castex, *Électricité médicale*, in both of which works the subject of body resistance is discussed at considerable length.

takes place as the skin becomes moistened and vascular, if this is not done there is a risk lest the current should become too great, and injury may result to the patient from want of attention. Burns of the skin are sometimes produced in this way.

160. **Diffusion of current in the body.**—When a current is led into a large conductor the lines of flow spread out through the conductor. They all pass from the anode to the kathode, but spread out in doing so. The current which passes across unit of sectional area taken at right angles to the lines of flow at that point may be called the density of the current at that point.

In a conductor like the human body it may be necessary to take into consideration the density of current at any particular point, because the physiological effects are partly dependent upon the density, that is upon the ratio of current to sectional area.

Dr. De Watteville says: "The reader may picture to himself the electrical density at any point of a circuit of variable diameter by representing the strength of a given current flowing through it by a certain number of lines. These lines expand in the wider portions of the circuit owing to the diffusion, and become crowded together in the narrower parts. A crowd issuing through a narrower door, and through gradually expanding passages, and finally reaching the street, like electricity flowing through a circuit of variable diameter, is said to be densest at the narrow exit, and it thins out, and has a lower density as it reaches the wider outlets."

The path of a current between two electrodes placed upon the body surface is not to be marked out simply by drawing direct lines from the one to the other, for the whole of the conducting tissues between the electrodes help to provide a passage for the current, which spreads out from beneath the positive electrode, becoming less and less dense as it occupies a wider and wider sectional area of the conductor, and again grows denser as its lines of passage become once more gathered together to reach the negative electrode.

Figure 108 shows the divergence of the directions of these lines of current as they pass from a positive electrode placed upon the back of the arm to reach the negative electrode placed somewhere upon the trunk, and it very well illustrates the fact that the current is not confined to the space directly between

the electrodes, for some of the lines which indicate its direction actually commence their course by curving downwards through the tissues below the electrode.

It follows that parts of the body which are outside the direct line of the electrodes may be influenced by the current passing between the electrodes.

It also follows that the size of the electrodes is of importance in treatment, for at the surface of contact of a small electrode the density of current per unit of surface, when a definite quantity of current is flowing, will be greater than when large electrodes are used.

FIG. 108.—Lines of current diffusion round positive electrode placed over the lower part of the arm.

161.—**Electrolytic conduction.**—It has been said that the body is an electrolytic conductor, and the terms used in considering the portion of a circuit in which electrolytic conduction is taking place have been shortly given in §§ 21-25. In the case of the ordinary electrodes used in medical treatment, the separation of the products of electrolysis takes place at the metallic surfaces, that is to say, in the moist chamois leather or other water-bearing material with which they are covered. These coverings, in fact, are made use of to absorb and, so to speak, to occlude the chemical products, in order to protect the skin from their action.

Diffusion, however, plays its part so that with prolonged applications, especially if the density of the current is great, the

chemical products of the electrolysis make themselves evident and exercise their proper chemical action upon the surface of the skin.

Uncovered electrodes would have a much greater effect, and would lead to injury of the skin much more rapidly, because with them the electrolytic products liberated by electrolysis are set free in immediate contact with the epidermal layer of the skin.

In an examination into the electrolysis of animal tissues, Dr. G. N. Stewart* showed that the whole of the conduction through animal tissues is electrolytic, and the electrolytes are the saline constituents. The variety of the saline constituents of the body is great, but the most abundant of them is sodium chloride. In order to simplify the consideration of the question we may for the moment regard the juices of the body as a dilute solution of sodium chloride of a strength of five parts in a thousand.

When a current is passed through the body by means of electrodes of covered metal, the chlorine ions part with their charges at the anode and tend to be liberated as chlorine, but owing to secondary reactions they may either enter into fresh combinations, with the setting free of HCl and oxygen, or they may combine with the metal of the anode to form compounds, such as chlorides, oxides, or oxychlorides ; the sodium ions are repelled and migrate inwards through the skin, on their way towards the kathode. Similarly at the kathode the sodium ions are attracted and tend to appear as metallic sodium, but owing to secondary reactions the products actually set free there are sodium hydrate and gaseous hydrogen, and the corresponding chlorine ions are repelled and migrate inwards through the skin to reach the anode.

This movement of ions has been very well illustrated by Leduc who connected two rabbits in series by means of a pad soaked in saline solution. On applying to the skin of the first rabbit an anode moistened with strychnine sulphate, the kathode on the second rabbit being moistened with a similar solution, he found that only the first animal was affected by the alkaloid, which migrated into its body from the anode, while the second animal remained unaffected during the time of the experiment, the ions migrating into its body from the kathode being harmless SO_4 ions.

* *Lancet*, December, 1890.

He then repeated the experiment with cyanide of potassium. In this case it was the rabbit at the kathode which was poisoned, the toxic constituent of the chemical used being the cyanogen ions migrating inwards from the kathode only.

Leduc attaches the greatest importance to the electrolytic effects of currents, he ascribes the variations in excitability of nerve and muscle to changes in the distribution of the ions, and explains the currents observed in the body, electrotonic effects, and so on, as due to movements and exchanges in the distribution of the ions existing in the various electrolytic solutions which constitute the living body.

In the case of a homogeneous electrolyte the products of electrolysis show themselves only at the poles, but in the more complex case of the human body it seems probable that chemical decompositions may take place within the tissues. At any rate it is certain that effects, probably chemical in their nature, are produced throughout the tissues of the body by the prolonged passage of a direct current. Within certain limits these effects can be undone by a reversal of the direction of the current, but if pushed too hard permanent damage is caused.

In the case of muscle the histological appearances undergo a change, the contractility may disappear, and degeneration and atrophy of the muscle may be the result. In support of the view that the changes are due to the electro-chemical effects of the current many experiments have been devised. Weiss, who has given much attention to this matter, attributes them to interpolar electrolysis, and has shown that a strong back electromotive force of polarisation can be obtained from tissues which have been subjected to the steady flow of a direct current. These polarisation effects imply the possession by the body of an electrolytic capacity, in virtue of which energy storage can take place in the tissues in the same sort of way as there is a storage of energy in a battery of accumulator cells (§ 42). Although the amount of energy thus stored is trifling, this electrolytic capacity of the body may become important through its effect in increasing the electrical capacity of the body, and in modifying the effects produced in some forms of electrical applications, especially with high frequency currents.

The electrolytic effects produced by currents are more conspicuous when needles plunged through the skin are used as the electrodes. This procedure is employed in medical practice as

a means of destroying tissues. Small moles, warts, nævi, &c., are got rid of in this way, and the technique of this form of surgical electrolysis will be described in a later chapter.

In the electrolysis of animal tissues with platinum needles the salts contained in the tissues split up with the result that alkalies are liberated at the kathode, and acids at the anode. As explained in § 25, the alkali metals formed in the first instance at the kathode decompose the water in its neighbourhood and sets free hydrogen, which appears as bubbles of gas. The caustic potash or soda thus produced saponifies the animal tissues and produces a soft deliquescent eschar, which is said to heal with less contraction than an eschar produced by either a wound, a burn, or an acid, and, therefore, is the most suitable to obtain when it is particularly necessary that the least possible contraction shall subsequently take place. The acids from the salts contained in the animal tissues appear at the anode in company with chlorine and oxygen, but the secondary reactions which take place there depend very much on the composition of the anode. If the electrode is made of zinc, chloride of zinc is formed, which exerts its own specific action on the tissues. By using anodes of iron or copper the local effects of salts of these metals can be produced.

The caustic effect of an electrode connected with the negative pole of a battery has advantages over the use of the ordinary caustic soda or potash. As pointed out by Dr. Poore, it can be applied to parts difficult of access, as the male urethra, or uterine cervical canal. It can be applied to these regions and others, such as the larynx, pharynx, or nasal duct, where the application of other caustics is attended with danger or difficulty. Its effects are limited to the points touched by the electrode. The duration and extent of the caustic action is entirely under the control of the operator.

162. **Electric osmosis. Cataphoresis.**—The fact has been long accepted that a movement of electrolytic fluids comparable to osmosis takes place in the direction of flow of the current, namely, from the positive to the negative pole; and that fluid can in this way be made to pass through membranes or porous diaphragms against the force of gravity; and it has been proposed to make use of this process for the introduction of drugs into the body through the skin. It is evident, however, from § 161, that the migration of the ions during electrolysis is also

an important factor in the introduction of drugs into the system by electric currents, and Leduc's work seems to show this is the only factor worthy of consideration.

To employ electricity is rather an elaborate method of administering a drug, and only in certain cases can it have any advantage over the methods of giving drugs by the mouth or hypodermically; besides, it is difficult to know when the proper quantity has passed into the system. It was hoped that in this way it would be possible to apply drugs locally, as for instance, iodide of potassium to a gumma, but this cannot be satisfactorily effected because the drug is carried of by the circulation quite as fast as it enters through the skin. Still, there are some particular objects which can be well and conveniently secured in this way, for instance, the introduction of cocaine to produce local anæsthesia of a portion of the skin, this can be done very simply by covering the positive electrode with a layer of absorbent cotton well moistened with a ten per cent. solution of cocaine hydrochlorate in guaiacol and holding it steadily to the part; with five milliampères of current the skin becomes anæsthetic in about five minutes. The procedure is of value before small superficial operations, and in neuralgic affections.

Other useful applications of electrical medication has been proposed; among them is one for the treatment of gouty deposits by salts of lithium. The affected part is immersed in a bath of warm solution of lithium chloride of a strength of two per cent. connected with the positive pole, the circuit is closed by a second warm bath containing a dilute solution of common salt in which the patient immerses some other indifferent part of his body. Currents of 25 milliampères for 20 or 30 minutes are used. Dr. Heyerdahl* has published some recent cases in which he carried out this treatment with good results. In France, Bordier† has introduced lithium into the system from an electrolytic bath (anodal) of lithium chloride, and claims further to have been able to detect in the bath, at the end of the operation, a certain amount of uric and oxalic acids derived from the tissues of the patient by the transport of anions of these bodies towards the positive pole. Dr. W. J. Morton, of New York, has published a treatise on the subject of cataphoresis dealing fully with its history, and its applications in medi-

* "Tidsskrift for den Norske lœge forening," Kristiania, May 15, 1899.

† *Arch. d'élect. médicale*, 1900, p. 529.

cine, surgery and dentistry* which should be consulted by those wishing to go deeply into the question.

163. **The capacity of the body.**—The human body regarded as a simple homogeneous conductor should have an average capacity, calculated from its extent of surface (§ 17), of ·000044 of a microfarad. Many experimenters who have examined this difficult question have found that the measured capacity is greater than this. It appears almost certain that the increase is to be attributed to polarisation effects of an electrolytic character, comparable to those which occur in a secondary cell or storage battery. The existence of this electrochemical capacity has been established by Weiss, and measurements of the actual capacity of the body have been made by many Continental experimenters. Thus Bordier estimates the capacity of the body at ·0025 microfarad, Dubois at ·165 microfarad, Wertheim Salomonson at ·0002 nearly, De Metz at ·0001. There is a considerable discrepancy between these values, and this may be due to the different methods employed, if we suppose that the capacity varies with some other factor, as for instance, with the electromotive forces applied during the operations for measuring its magnitude.

A very instructive account of the methods of measurement employed by different experimenters will be found in Prof. Castex's recent book,† from which this paragraph is mainly derived. In one of the experiments of Wertheim Salomonson there detailed, the influence of the capacity of the body upon its apparent resistance to high frequency currents had the effect of reducing the value to 373 ohms, although the resistance when measured by a direct battery current had a value of 2000 ohms.

The influence of the capacity of the body in high frequency work is further illustrated by the following experiment:—Four persons, hand in hand, were connected to one pole to a high-frequency apparatus, and the current was measured. Between the pole of the apparatus and the first subject a current of 151 milliampères was registered; between the first and second the current was 132, and between the second and third 128 milliampères.

164. **Electrical phenomena of nerve and muscle.**—Nerve and muscle act as conductors, whether they be alive or

* "Cataphoresis or Electric Medicamental Diffusion," New York, 1898.

† "Électricité médicale," E. Castex, Paris, 1803.

dead; they conduct more readily along the length of their fibres than across them, and Brenner has shown that in nerve the transverse resistance is as 5 : 1, and in muscle as of 9 : 1, as compared with their longitudinal resistances. It is probable that these differences in resistance simply signify that as conductors they are not homogeneous.

Electrical currents have been demonstrated in nerve and muscle, and also in glands, in skin, and other living tissues.

If the wires of a sensitive galvanometer be attached to two points in a removed portion of either nerve or muscle, the existence of a current will be made manifest by the deflection of the galvanometer needle, its direction being that which indicates a current passing through the wire from the central part of the piece of nerve to its extremities; this current is called the *current of rest.* It is more easily demonstrated in an excised and therefore damaged portion of nerve or muscle than in a part which is still lying uncut in the body; and it is suggested that this current of rest only exists in damaged tissue, and is set up by chemical changes resulting from the injury.

If while the galvanometer is attached to it, the nerve or muscle be stimulated in any way, whether by electrical, mechanical, chemical, thermal, or any other means, then the galvanometer needle will give evidence of the production of an electrical current by a momentary deflection in the opposite direction to that produced by the current of rest; this has been called the *negative variation* of the current, or the *current of action.* It is propagated in both directions from the point stimulated, and travels in nerve at the rate of 28 metres per second, and in muscle at three metres per second, that is to say, the disturbance of equilibrium producing the current moves at these speeds, which are very much slower than the rate at which an electrical current travels along a nerve, which is an entirely different thing. The impulse which passes along a nerve to cause muscular contractions or sensory impressions is not an electrical impulse, although there is an electrical change associated with it. If a nervous impulse were simply an electrical current it should be transmissible by an electrical conductor, as for instance a copper wire, but it is not so transmitted, neither will a piece of damaged nerve convey a nervous impulse, although it may readily convey an electrical current; moreover, the velocity of an electrical current in a conductor, such as a

nerve trunk, is immensely more rapid than the velocity of a nervous impulse in a nerve trunk. In muscle the current of action is propagated at the rate of three metres per second. D'Arsonval considers the current of rest as a real current existing in living tissues, apart from all question of injury, and produced by the interaction of oxidisable bodies with the oxygen of the plasma. The formation of heat in living tissues is due, in his opinion, to the effect of these electrical currents.

165. **Electrotonus.**—During the passage of a steady current along a nerve certain alterations in the irritability of the nerve and in its conductivity are produced, and this altered state is known under the name of electrotonus. Electrotonus is the condition of a nerve during the passage through it of a constant current, but the effects in that part of the nerve near the anode are not the same as those near the kathode, thus there is one altered state round the anode of anelectrotonus and another different altered state round the kathode of kathelectrotonus.

In the region of the anode the irritability of the nerve is diminished, the fall in irritability taking place at the moment when the circuit is closed, and remaining diminished till the circuit is again opened, when there is a return to the normal. Also the conductivity of the nerve for nervous impulses becomes diminished by the development round the anode of a resisting area through which nerve impulses pass only with difficulty.

Round the kathode the closure of the circuit causes a rise of irritability which is maintained during the passage of the current, and returns to the normal level when the current has ceased to flow. The sudden rise of irritability at the kathode on closure is a stimulus to the nerve, and so also in a less degree is the rise from a diminished irritability to the normal at the anode on opening. The importance of electrotonus partly lies in the explanation which it affords us of the behaviour of muscle towards constant currents, at their make (closure) and break (opening). Electrotonus is also useful medically by providing a clue to the treatment of disease; accordingly where it is wished to increase the irritability of a part the condition of kathelectrotonus should be set up by applications of the kathode, and conversely the application of the anode is to be preferred for inducing a state of diminished excitability, and so of relieving pain and spasm.

166. **Reactions of nerve and muscle.**—The behaviour of nerve and muscle to electrical stimuli under conditions of experiments with dissected tissues will be found in works on physiology. In the living subject the phenomena observed under conditions of electrical testing and treatment are as follows:—If the indifferent electrode (§ 76) be placed upon any convenient part of the surface of the body, and the testing electrode (fig. 44) be then applied over a superficial motor nerve, as the ulnar at the elbow, it will be found that with a current of one milliampère from a battery, muscular contractions begin to be visible when the circuit is closed, and with stronger currents contractions appear both on closing and on opening the circuit. With the active electrode negative the contraction at make or closure is easier to produce than when it is positive. The order in which they appear are:—

1. Kathodal closing contraction (KCC).
2. Anodal ,, ,, (ACC).
3. Anodal opening contraction (AOC).
4. Kathodal ,, ,, (KOC).

The symbols affixed are commonly used for convenience to designate the contractions.

The exact current needed to produce muscular contractions by stimulating a motor nerve trunk varies with its position; a nerve which is superficially situated is affected by a smaller current than a deep-seated one, because it receives a greater fraction of the current; in the case of a deep-seated nerve the current undergoes diffusion before it reaches the nerve, so that only a part of the current indicated by the galvanometer traverses it effectively. For the same reason a patient with a thick layer of subcutaneous fat requires a larger current to provoke muscular contractions than is the case with a lean person in whom the electrode can be brought into closer proximity to the nerve to be stimulated. The testing electrode should be of small surface, as this allows us to concentrate the current more effectually. There is probably not very much difference in the irritability in different nerve trunks, but it has been suggested that the facial nerve may be slightly more irritable than others. This certainly appears to be the case, and the facial muscles can be thrown into contraction by smaller currents than those of the trunk and limbs. The sensory nerve supply of the face also responds very strongly to electrical stimulation, so that in

applications to the face, for testing or for treatment, the currents must be kept low.

Dr. Verhoogen* gives the following figures for the contractions produced by stimulating the ulnar nerve behind the internal condyle of the humerus:—

KCC	2	milliampères.
ACC	3	,,
AOC	3·5	,,
KOC	15	,,

And these may be taken as representing very well the approximate magnitudes of current necessary to evoke the contractions of healthy muscles through their motor nerve trunks.

These figures are of value because they give the actual effects observed in a particular case, but they seem to be rather high; other observers have found one milliampère to be a sufficient magnitude of current for producing the minimal KCC contraction in superficially placed nerves.

It has lately been shown by Dr. Ludwig Mann, of Breslau, that the nerves of infants and young children require currents of considerably greater magnitude to provoke contraction in their muscles.

Erb has suggested that it is convenient to make use of certain nerve trunks which can easily be reached when the electrical condition of the motor nerves is to be tested. He chooses for the purpose the frontal branch of the facial nerve, the spinal accessory in the neck; the ulnar, and the peroneal; a standard size of electrode should also be used, and a disc three-quarters of an inch in diameter is a suitable one.

In a normal muscle the effect of direct stimulation of its fibres is overshadowed by the effect produced upon it through its nerves, for the intramuscular branches of its nerve both receive the impression better, and transmit it to all parts of the muscle more rapidly than the muscular fibres themselves could do it if no nerves were present. Still muscle *per se* is irritable and capable of responding to stimuli by a contraction; and a muscle whose nerves have undergone injury may still respond to currents directly applied, although unaffected by stimuli applied to its motor nerve (see following chapter, "Reaction of Degeneration").

The contractions produced in muscle by the stimulus of the

* *Revue internationale d'électrothérapie*, September, 1894.

make and break of a direct current are momentary single contractions, and between the contraction at make and the contraction at break the muscle appears quiescent and relaxed, although the current is traversing it. As a matter of fact it is not completely relaxed, and a small "contraction remainder" can be observed by appropriate methods of investigation, and the larger the currents the greater will this degree of contraction be. With strong currents a condition of imperfect tetanus is produced, which has been named "duration tetanus." Anodal duration tetanus, ADT, is less common than kathodal, KDT. The duration tetanus is not usually seen in healthy muscles with the currents used in electrical testing, but in certain altered conditions it is more readily elicited than in health, and it will be considered in the next chapter.

If the makes and breaks of a battery current follow one another in rapid succession, the muscle passes into a state of of tetanus or permanent contraction. To produce this effect the individual shocks must succeed one another at the rate of twenty per second or upwards.

As the discharge from an induction coil consists of a series of impulses or waves of current (§ 59) occurring about fifty times a second, it is reasonable to expect that their effect upon a motor nerve would be to throw the muscles into a tetanic contraction, and that is what is observed. If the induction coil be arranged to give single shocks, single contractions follow, exactly like those produced at the closure of a battery current, each wave of current from a coil acting as a separate stimulus, but ordinarily the effects are fused by the comparative slowness of the muscular contraction, which requires one-tenth of a second for its completion.

The rise and fall of the waves of current from an induction coil are less sudden than the rise or fall when a battery current is made or broken. The current from a battery rises to its full value at the make and falls again at the break instantaneously, while the rise and fall of the current from a coil is gradual, as shown in § 64, and the current wave may occupy a period of one-hundredth of a second.

It has already been said that a muscle can be thrown into contraction by an electrical stimulus equally well, whether the stimulus be applied through the motor nerve trunk or directly to the muscle itself. Under conditions of health, stimuli to the

muscle are really stimuli through the motor nerves of the muscle. In practical electrical testing it is usual to apply the electrodes to the muscles directly at their motor points, whose position will be indicated in the next chapter. The individual behaviour of the muscles is more clearly seen by this method than if they be thrown into contraction in groups, as generally happens with stimuli applied to a nerve trunk which supplies a number of separate muscles.

The study of the effect of electrical stimuli upon nerve and muscle has been complicated by the adoption of the induction coil as the usual source of interrupted currents. Induction coil discharges are impulses or waves of irregular form and very variable duration, and are by no means the instantaneous discharges which they have been too commonly assumed to be. The disadvantages under which induction coil currents labour may be learnt from what has been written on the subject in Chapter III. In recent years the exact character of the electrical stimuli used in electrical testing and treatment have attracted much attention. Hoorweg, Dubois, Huet, Mendelssohn, and others, have attacked the problem in various ways, but there is still much work waiting to be done. D'Arsonval throughout all his researches has insisted on the importance of the form of the wave of an electric impulse in any study of its physiological effect. Dubois has shown that comparatively slight alterations in the self-induction of a circuit exercise a marked effect upon the current required to provoke the minimal contraction in a muscle, simply through altering the wave form of the current by retarding its rate of rise. A galvanometer in the testing circuit has sufficient self-induction to modify the effects of a test in this way.

Leduc has recently published an important paper on the production of muscular contractions by interrupted currents. In his experiments, a direct current is interrupted by a revolving commutator. In this way he is able to obtain currents of known duration, and of known magnitude, the duration of the intervals is also known, and his results have, therefore, a value which is superior to any which can be obtained by induction coil currents. He finds that the electromotive force necessary to produce a minimal contraction is least when the time of flow, or duration of each current impulse, is one thousandth of a second; the duration of the intervals of no current has an

important influence upon the contractions. A tetanising effect demands a certain minimal duration of the interval. With intervals shorter than this, the rapidly interrupted current gives closing contractions, suggesting those of a steady uninterrupted current.*

167. **Condenser discharges.**—Condenser discharges have also been used as stimuli to nerve and muscle. Boudet de Pâris, in 1888, advocated their employment, and in his book points out that condenser discharges cause little or no fatigue in muscle, and he also gives plans of the arrangement of a condenser apparatus for muscle testing. Hoorweg† also gives an account of the mode of employment of condensers. Both these writers have endeavoured to determine what has been called the "characteristic" of nerve and muscle, meaning, thereby, an attempt to determine some relationship between the amount of muscular effect, and the amount of electric energy causing it. The electromotive force, the current, and the watts of an exciting current have all been scrutinised from this point of view. It is probable that the electrical stimulus which sets up a muscular contraction should be regarded as energy expended in pulling the trigger of a gun, rather than as the energy expended in propelling the bullet, and, therefore, no direct relationship between the energy of the stimulus and the energy of the muscular contraction can be expected. Dubois,‡ in considering the behaviour of muscle and nerve to condenser discharges, points out that inasmuch as the phenomena of muscular contraction can be produced equally well by battery currents, or by discharges from an induction coil, a static machine, or a condenser, there is probably some condition common to all these modes of stimulation. He states that experiments with condenser discharges show that as the charging potential is increased, the required capacity of the condenser decreases rapidly; for example, the minimal contraction in the muscles of man is obtained with a capacity of 0·48 microfarads charged at 12·6 volts, with 0·017 at 35 volts, and with 0·007 at 70 volts, the capacity in the last example being seventy times less than in the first, while the potential is only six times greater. In man a minimum potential of about 12 volts is

* *Arch. d'électricité médicale*, September, 1903.

† *Recherches sur l'excitation électrique des nerfs*, Haarlem, 1899.

‡ *Rev. internat. d'électrothérapie*, August, 1900.

necessary, and discharges at lower potentials are ineffective, whatever the capacity of the condenser. If the energy of the condenser discharges be calculated, it appears that at low potentials it is relatively large; that as the potential is raised, and the capacity is diminished, the energy required becomes less until a point is reached, after which it again increases; there is a relation between potential and capacity, such that a point can be found at which the minimal contraction is produced with a minimum expenditure of energy. Energy is wasted in the case of the large condenser at low potential, because much of the discharge is below the effective minimum; while in the case of a small condenser and a high potential there is waste, because the duration of the discharge is too short. In the case of a large capacity and a low potential, the rate of discharge may also be too gradual to be effective, owing to the resistance of the patient's skin. The view of Dubois-Reymond, that the effect on a muscle varies simply with the magnitude and rate of change of the stimulating current, holds good to a modified extent only. The discharge of a Tesla coil fails because the individual impulses, of which it is made up, have too short a duration.

Dubois' experiments appear to emphasise the relationship between the wave form of the stimulus and the physiological effect. The discharge of a small condenser at a high potential is a peaked sudden wave of short duration, that of a large condenser at low potential is a wave of lower peak and long duration, the former is the more effective stimulus, unless, as in the case of the high frequency apparatus, its duration is so short, as to leave the nerve or the muscle uninfluenced.

Condenser discharges have the advantage that a condenser of known capacity, when charged to a known voltage, contains a known quantity of electricity, but in experiments with condensers, the resistance of the discharge circuit determines the initial value of the discharge, and also its duration, and, therefore, requires careful measurements if correct results are to be obtained.

Waller* has also employed condensers for the examination of motor and sensory phenomena, and gives some very interesting tables to show the reciprocal effects of variations in the magnitudes of capacity and electromotive force upon motor and sensory nerves.

* *Proc. Roy. Soc.*, July, 1899.

The important part of a condenser discharge is its commencement, and the magnitude of the current at that instant is determined by the resistance of the discharging circuit, particularly in the case under consideration of the testing of nerve and muscle. If the circuit include coils of wire, the self-induction of the circuit would also become an important factor in modifying the instantaneous value at the commencement of the discharge.

168. **Effect of curare and strophanthine.**—The effect of curare in rendering the muscles inexcitable through the motor nerves has long been known. It was discovered by Claude Bernard. In a curarised animal, stimuli applied directly to the muscles are able to produce contractions, though stimuli applied through the motor nerves are not. A curarised muscle will react to interrupted currents as well as to battery currents, and the contractions produced only differ from those of a normal muscle in being a little less brisk.

Strophanthine also modifies the muscular contractions. When injected into a frog, it predisposes to the production of duration tetanus (§ 166), so that a steady current easily provokes a tetanic contraction, which may persist for a little while after the current has ceased to flow.

169. **Unstriped muscle.** — The behaviour of unstriped muscle differs from that of striped in that its latent period is much longer, and the rate of contraction is also longer. When the muscular coat of the intestine is stimulated it may contract locally and remain so, or waves of peristaltic contraction may start from the point stimulated and travel slowly towards the remoter parts of the bowel. It is said that the anode is the more effective pole for stimulating unstriped muscle.

The most effective means for setting up contractions in an organ containing unstriped muscle is to use the battery current slowly made and interrupted, or better still to employ reversals of the battery current.

170. **Heart muscle.**—The habits of heart muscle are peculiar in their highly developed tendency to rhythmic contractions; electric stimulation tends to strengthen the action of heart muscle if it be timed to suit the natural rate of the rhythm; if the stimulation does not quite keep time with the heart beat it may effect a gradual change in its rate, until the heart may be brought to beat in time with the rate of the stimulation. If the stimulation be quite out of step with the rhythm

of the heart it will tend to embarrass its action. A weak or moderate continuous current or a smooth unbroken succession of induction coil shocks may strengthen or accelerate the beat of the heart. Strong continuous currents destroy the rhythm of the heart, and cause it to stop in diastole, see below, § 178, and strong shocks from an induction coil do the same. The useful employment of electricity to strengthen a heart which has suddenly developed signs of failure is very difficult, and there is considerable risk of doing the patient more harm than good by injudicious electrification.

171. **The sensation of shock.**—This effect seems to depend partly upon the magnitude of the current, and partly upon the rate of change in this magnitude. It is possible to tolerate the gradual introduction or the steady passage of twenty or thirty milliampères through the body if the contacts with the skin at the electrodes are large and good, but if currents of five milliampères are rapidly set up in the body, the sensation of shock is severe, and when a current is broken rapidly its sudden cessation also produces a far greater impression than that felt while it is running steadily. This shock at the break or opening of the circuit is difficult of explanation, and nothing comparable to it is observed with inanimate electrical circuits or apparatus, for it is not of the nature of an electro-magnetic induction effect; the explanation which is offered in physiological textbooks, namely, that a sudden fall of potential is an effective stimulus to a nerve fibre is no explanation at all.

The important part played by the rate of change of current in producing physiological effects is clearly shown by what has just been said of the current slowly or suddenly made and broken through a circuit which includes the body; the part played by the quantity of current passing is seen by a comparison of the effects of a spark drawn from the prime conductor of an electrical machine with that from a Leyden jar discharge. A spark a quarter of an inch long taken from the former produces only a slight impression, but a spark of the same length from the jar gives a violent shock. The difference between the two is largely a difference in quantity of current passing. In both cases the electromotive force is equally high, but in the case of the Leyden jar there is, for the extremely brief instant of the discharge, a fairly large current, because of its capacity as a condenser.

172. **Sensory nerves.**—Just as the electrical stimulation of motor nerves causes muscular contractions, so the stimulation of sensory nerves produces sensations. Accordingly, when an ordinary mixed nerve trunk is stimulated, its motor fibres set up contractions in the muscles supplied by it, and its sensory fibres convey to the brain of the patient experimented upon a peculiar sensation, strong or weak, in proportion as the current is strong or weak. The peculiarity of the sensation also produces a mental effect, so that different patients appear to vary in their susceptibility to these sensations, thus it is said that if a current be transmitted from hand to hand through a line of people, some will say they felt the shock severely, and some only slightly.

In the case of the direct current, there is a sensation not only at closure and opening, but also during its steady passage, if the current be fairly strong, but not if it be weak.

The sensations are more perceptible at the kathode than at the anode, but a good deal depends upon the relative sizes of the electrodes; if one be much smaller than the other, then the greater density of current at the smaller one increases the cutaneous sensations there. If the electrodes be held still in one place, other sensations of a burning character soon become felt, and are accompanied by reddening, urticaria, or blistering of the surface; these changes and the burning pain are due to the formation of chemical products by electrolysis. In the removal of hairs by electrolysis, the fine needle-like electrode introduced into the hair follicle feels much as though it were very hot. The nature of the surface of the electrode also modifies the sensation; and the current is less painful when the electrodes are firmly pressed upon the surface, because the contact is then better and the current is distributed over more points of entrance.

Bare metal electrodes applied to the skin produce injury to its surface more quickly than do those covered with a layer of moistened wash-leather, or flannel, or the like, because in the former case the products of electrolysis are set free at the actual surface of the skin, while in the latter they are formed chiefly in the moist material which covers the electrode. With battery currents care must be taken to protect the skin from all accidental contacts with bare metal.

A single discharge from an induction coil produces a sensa-

tion like that of a sudden make or break of a battery current, the severity of the shock depending upon the electromotive force and current in the circuit. An induction coil with its contact-breaker in action, produces a series of shocks in which the individual impulses may be perceived, unless they follow one another too rapidly.

At fifty interruptions per second the sensations begin to become fused, and at higher rates of vibration the sensation feels more smooth or continuous than before. With rapid vibrations, one hundred per second and upwards, a benumbing effect becomes noticeable in the area of distribution of a cutaneous sensory nerve, if the electrode be applied to a point upon its trunk ; this sensation of numbness being in addition to the effect felt in the place of contact of the electrode. With a small movement of the electrode away from the nerve trunk the numb feeling may disappear. The numbness is a true anæsthesia, both tactile sensations and the perception of painful impressions being very greatly blunted, and a glow accompanied by perspiration often succeeds, when the current is cut off.

When an electrode is moved over the surface of the skin systematically, the position of the cutaneous nerves can often be exactly localised by using a very small electrode and a current which can just be felt, for whenever the electrode comes close over a sensory nerve trunk the sensation at once becomes quite strongly felt ; from this it appears that a nerve trunk is more sensitive to the stimulation than the nerve endings are. In testing muscles it is of advantage to know the position of these "sensory points," in order to avoid them and save the patient from unnecessary pain. On the dorsum of the foot there are several, which are apt to become painfully stimulated when testing the electrical reactions of the interosseal muscles. A little exploration of one's own cutaneous surface affords the best way of learning the position of these superficial nerve trunks.

It is stated by Erb that the perception of the induction coil current is a function similar to the perception of painful sensations, rather than of tactile. This can be clearly seen in patients who have analgesia, without loss of tactile sensibility. In hysterical cases it may sometimes be noticed that a patient who can feel the touch of the electrode quite well, feels no shock at all, even with very strong currents.

Perhaps the word "shock" should really be confined to those forms of electrical sensation in which there is muscular contraction, for the muscular sensation contributes largely to the peculiar feeling connoted by the word shock.

173. **Nerves of special sense.**—The nerves of special sense respond to electrical stimulation by their own special sensations, thus stimulation of the olfactory nerve is said to produce a smell "like phosphorus," and stimulation of the optic nerve produces the impression of a flash of light. The optic nerve seems to be remarkably sensitive to small electrical currents, and the sensation of a flash of light is very easily produced by the small current obtained from a silver coin and a piece of zinc put into the mouth between the gums and cheek. When the metals are made to touch, the optical effect is distinct. Some observers have even thought that the colour of the flash seemed to depend upon the direction of the current, and that the kathodal closure gave a reddish colour, and anodal closure a bluish one. These effects can be studied with one pole at the nape of the neck, and the other over the eyelids. In making experiments on the eye, one may usefully bear in mind the accident which befell Duchenne, who apparently caused very serious damage to the sight of one of his patient's eyes, when applying a strong current to his face. The effect may have been a retinal hæmorrhage due indirectly to the electrical application. Duchenne's observation, that the current of the secondary coil acts on the retina more strongly than that of the primary, seems to be due to the longer duration of the waves in the former case. Waller* also suggests that longer stimuli are better adapted to the excitability of the retina, and shorter stimuli to the excitability of common sensory terminal organs.

The auditory nerve can also be made to respond to stimulation by direct current. In healthy individuals it is not very easy to produce the electrical reactions of the auditory nerve, for fairly strong currents are required, and the associated effects upon the face and eyes and brain make the experiment unpleasant; but the investigation is important, because of its bearing upon the treatment of tinnitus aurium. There is a close likeness between the formula of the auditory nerve, and that of the other nerves. The kathodal closure most readily produces a sensation of sound, which may continue during the passage of the current, but the

* *Proc. Roy. Soc.*, July 27, 1899.

anodal closure does not do it so easily; on the other hand the anodal opening produces a sound, and kathodal opening does not.

These auditory phenomena will be again referred to in a later chapter.

It is easy to stimulate the nerves of taste, and the simple experiment just mentioned for producing the optical sensation of a flash of light, will at the same time produce a metallic taste, and the same metallic taste is produced by passing a current from one pole at the back of the neck to the other placed below the chin.

174. **The brain.**—In the case of the brain, experimental physiologists have made much use of electrical stimuli in determining the situation of motor centres in the exposed cerebral cortex. In ordinary electrical applications it is found that when a continuous current is passed transversely through the skull, with the electrodes on the temples or mastoid processes, there is a disturbance of equilibrium, producing a feeling of giddiness, or an actual unsteadiness, with a tendency to fall towards the side of the anode, and sometimes there is conjugate deviation of the eyes to the side of the kathode, with a kind of oscillation or lateral nystagmus.

It has been supposed that the disturbance of equilibrium depends upon a state of kathelectrotonus of one hemisphere, with anelectrotonus of the other; the former hemisphere being in a state of exalted excitability, and the latter in a state of diminished excitability, their action is no longer balanced, and a sensation of giddiness is the result.

The brain is not easily influenced by induction coil currents applied to the outside of the skull, though responding readily when the electrodes are applied directly to its substance, but this is probably to be explained by the fact that induction currents of the required strength are so painful to the skin, as to be badly borne.

In the *Comptes Rendus* for 1902, Leduc published an account of some remarkable effects produced by rapidly interrupted currents passed longitudinally through the nerve centres.* The anode was placed on the hinder part of the back of a dog, and the kathode on the skull. The skin was previously shaved. The current was increased gradually, and at a certain strength general convulsions set in, the animal became unconscious, the

* "On the induction of sleep and anæsthesia by electrical currents."

sphincters were relaxed, and respiration ceased. When this stage was reached, the current could be reduced in part, and respiration then recommenced, and a state of tranquil sleep was induced, in which the animal remained until the current was arrested. During this period of sleep there was anæsthesia. No injurious results seemed to follow, and as soon as the current is stopped the animal jumps up and seems quite well. Later writers, in commenting upon Leduc's experiments, appear to regard the phenomena as due to the induction of an epileptic state by the electrical current.

175. **Other organs.**—Besides the physiological action of electricity upon the nervous and muscular tissues, it has an action on secreting glands, upon the viscera, and in fact upon all living protoplasm. It is quite in accordance with what one would naturally expect, that a current passing through a secreting gland, or through its nerves, should cause increased secretory activity; and that a current passing through a viscus containing unstriped muscle, should cause peristaltic contractions of that viscus, and there is no need to enter into detail at present by describing the particular behaviour of the uterus, of the bladder, or of the intestine, for these points will be better treated of later.

176. **Trophic effects.**—Experiments were made by Dr. Beard* to determine the effect of "general faradization" upon the growth of young dogs, and they were kept under treatment for four weeks, being treated daily with an induction coil current; at the end of the time the two animals which had been so treated had gained in weight faster, and were perceptibly bigger than two others, which had been kept untreated as control animals.

D'Arsonval has also examined the trophic effects of electrical applications of various kinds, and has made the following summary of his results.†

1. Under the influence of static treatment there is a slight increase of respiratory exchanges. This is not due to the presence of ozone around the patient, for it is not noticed if the patient is placed in the neighbourhood of the machine without being electrically connected with it.

2. Induction coil currents, by producing more or less extensive

* Beard and Rockwell, "Medical and Surgical Uses of Electricity."

† *Rev. Int. d'électrothérapie*, May, 1893.

muscular contractions, augment the oxidation processes of the body. By severe tetanisation of all the muscles of the body, the temperature of the body can be so raised as to lead to the death of an animal from that cause. Induction coil currents, even when so gentle as to cause no muscular contraction, can nevertheless cause modifications in the nutritive exchanges of the body, with increased production of heat.

3. The direct current, on the other hand, in spite of the general belief in its trophic effects, has given negative results, both in experiments on man and upon animals, so far as an effect upon respiratory exchanges is concerned. It may perhaps have an influence upon cellular activity.

4. The sinusoidal current has shown the most marked effect. By its use one can augment, by 25 per cent., the respiratory exchanges, and that without provoking any muscular contractions whatever. This result is found both in men and in animals.

Debedat* has studied the relative effects of various forms of electrical stimulation upon growth. His experiments were made on the muscles of young rabbits with the various kinds of electric applications used in medical treatment. The group of hamstring muscles was chosen; those of the left side were stimulated in various ways daily during twenty days, for four minutes a day; those of the right side were left for purposes of comparison. At the end of the period the animals were killed, and the muscles of the two sides carefully removed and weighed; portions were also hardened, and examined microscopically. The modes of stimulation were as follows:—1. The induction coil current with rhythmic periods lasting for one second, and followed by one second of interval, and so on for four minutes. 2. The battery current of two milliampères, with the same periods of stimulation and repose. 3. Electrostatic sparks, two to three millimetres long, repeated every two seconds. 4. Tetanisation of muscles for four minutes, by means of an induction coil, without any intervals of repose. 5. Steady battery current for four minutes, without intervals of repose.

The results showed a gain of 40 per cent. in weight on the stimulated side with the rhythmic induction shocks, and of 18 per cent. with the rhythmic battery current. The prolonged tetanisation caused a marked loss of weight; the prolonged steady battery current a slight increase in weight. Adhesions

* *Arch. d'électricité médicale*, Feb. and March, 1894.

had been formed between the skin and the muscle, at the points of application of the electrodes in this way. The gain in weight was due to a true growth of the muscle; the loss was accompanied by histological evidence of damage to the muscle fibres. The static sparks had no effect. The author concludes that the most advantageous mode of promoting the growth of muscle by electricity, is to use an induction coil, and to arrange the periods of contraction and repose of the muscle, so as to approximate to the conditions of a muscle during the performance of rhythmic gymnastic movements—namely, about thirty periods of contraction, and thirty of rest per minute, prolonged tetanisation being distinctly hurtful.

177. **"The refreshing action" of the galvanic current.**—Dr. G. V. Poore* has reported some remarkable experiments upon what has been called by Heidenhain, "the refreshing action" of the constant current; he investigated the fatigue of muscles, produced when a weight is held out steadily at arm's length, and gives an instance of a patient who was able to hold out his arm horizontally, with a weight of seventeen ounces in the palm, for a period of four minutes, and then complained of great pain in the muscles, and fatigue, and declared his inability to go on, but was relieved of his pain at once by the passage of a constant current in a descending direction along the arm. Another person was then experimented on in the same way; after holding out the weight at arm's length for seventy seconds, he felt pain and fatigue, but the application of the current at once removed both, and he continued to support the weight for five minutes and a quarter, and at the end of that time was willing to go on longer. Dr. Poore says: "similar experiments to these have been tried on several of the author's friends, and they all tend to show that the endurance of voluntary muscular action is enormously increased by the passage of a constant current, and the feeling of fatigue, both during and after the prolonged effort, is mitigated or entirely obviated.

Dr. Poore also demonstrated that the force as well as the endurance of a muscular effort could be increased by a galvanic current. Eight successive squeezes with a dynamometer, at intervals of ten seconds, gave an average of 48½ pounds for each squeeze, but eight more squeezes, with the aid of the current, gave an average of 59½ pounds, although they came ten minutes

* "Electricity in Medicine and Surgery," Dr. G. V. Poore, London, 1876.

after the first series, and while there was distinct consciousness of fatigue from the first experiment.

The current used was never strong enough to produce involuntary contraction of the muscles.

Capriati* has more recently examined this matter with the aid of scientific methods of measurement. He has found that the direct current applied along the spine increases the muscular force of an individual, and that such increase persists for one or more days afterwards. Similar results followed applications of direct current to the limb tested, but were less marked; and finally they may also be observed after electrification by static charging. The direction of the current, or the polarity of the charging, appear to have had little or no importance. The magnitude of current used in the first experiments on the spine was 10 to 15 milliampères.

178. **Death from electric shock.**—The fatal effect of

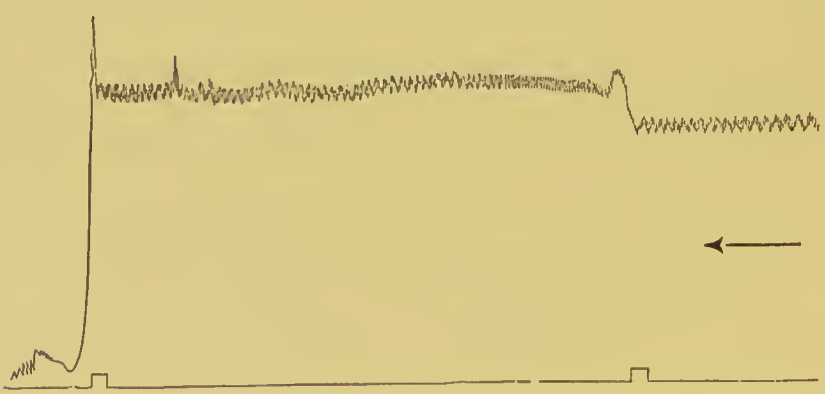


FIG. 109.—Blood-pressure tracing, showing effect of electric shock through skull and through thorax of a cat.

FIG. 110.—Failure of respiration after stoppage of the heart from electric shock.

powerful currents is due, in many cases, to stoppage of the action of the heart, which falls into a condition of irregular fibrillar twitching, from which it seems unable to recover, and quickly stops altogether. The tracings (figs. 109, 110) show the results in some experiments upon cats under chloroform. In the first is seen the rapid fall of blood-pressure to zero after the

* "Influence de l'électricité sur la force musculaire," *Arch. d'élect. médicale*, 1899, p. 522.

passage of a current of half an ampère transversely through the thorax. A current of the same magnitude through the skull produced a trifling effect, with increase of blood-pressure, which is seen in the first part of the same tracing. In the other figure is seen the secondary effect upon respiration, caused by the failure of the blood supply in the respiratory centre. These tracings were taken during some experiments with the direct current. Oliver and Bolam have more recently published tracings showing that with alternating currents the results are similar. To cause death, the currents must have a certain minimal value, and must traverse a vital organ, the heart being the most susceptible.

The most important researches upon the cause of death from electric currents are those made by MM. Prevost and Battelli,* and a valuable summary of their work will be found in the *Arch. d'élect. médicale*, 1902, p. 777, by Battelli. A very peculiar point is brought out in their researches, viz., that electric currents may kill in two distinct ways, that is to say either by a direct effect upon the heart, like that shown in the tracings just given, or by an entirely different effect upon the central nervous system causing an arrest of respiration, the beating of the heart remaining unaffected. Battelli states that with low pressures (small currents) death occurs, in the first manner, through the heart. Among animals certain differences of susceptibility are observed. In dogs, for instance, the arrest of the heart's beat is final and proves fatal; in guinea pigs and in rabbits the heart's beat is arrested and fibrillar twitchings are produced, but the natural beating may be resumed. In rats an arrest with fibrillar twitchings is produced, but lasts only so long as the current is passing, so that in these animals the heart recommences to beat in a normal manner as soon as the current is switched off, and they are not killed by stoppage of the heart. Strange to say this effect of currents in arresting the heart is more evident with small than with large currents, and is not observed with very large currents, so that Prof. Battelli even states that a heart arrested by an electric shock of small magnitude can be caused to recommence beating by a current of large magnitude sent through it afterwards. When the currents are large it is the central nervous system which is the most affected, consequently in cases of accident from contact with high pres-

* *Comptes Rendus*, March 27, 1899.

sure conductors, and when large currents have traversed the patient's body, the heart beat may not be arrested, but there may be a profound inhibition of the respiratory centre. As the arrest of respiration is not inevitably fatal, but may be recovered from, either with or without the help of artificial respiration, it follows that beyond a certain point danger is decreased rather than increased with increase of current through the body. If this view is correct it may account for some of the sensational non-fatal accidents which have happened of late years with very high tension currents.

The views of D'Arsonval that electric shocks prove fatal by arrest of respiration are thus seen to be correct in certain cases only. It is probable that the fatal accidents are generally cases in which the heart has been arrested, while the severe but non-fatal cases have suffered through shock to the nerve centres, with temporary arrest of respiration, but their hearts have escaped.

In the absence of direct observations the minimum fatal current for human beings may be estimated at about one-half to one ampère. The most common path of the discharge is from one conductor to earth through the body, but the current may also pass directly from the body to the other conductor of the system. In the first case the point of exit is generally by the feet. Burns of the skin should always be looked for at the points of entry and of exit; they may be severe or slight. When the current goes to earth through the feet these may not show signs of burning if the foot covering is damp. The severity of the burns is proportional to the duration of the discharge. Most of the fatal accidents have been with potentials above one thousand volts. Experience has shown that the body may carry a current sufficient to produce extensive burning at the points of contact, without causing death, and this may be the case even when the current has fairly traversed the trunk. In a recent accident in London two men were concerned and the current passed from the live conductor to the first man, and from him through the second to earth. The first man survived though the second was killed. The relative danger of alternating and direct currents is not decided; there is probably no great difference. Batelli considers that there is diminution of danger with increase of frequency when alternating currents are concerned. (See also §§ 108-151).

179. **Thermal effects.**—With the small currents used in medicine there is no appreciable heating of the tissues. A slight warmth can be felt over a nævus during its electrolysis. In cases where death has been caused by the passage through the body of the powerful currents used for electric lighting, well marked evidence of a rise of temperature has been observed, but the rise of temperature in these cases may be due to the excessive production of heat by prolonged muscular tetanus.

180. **Electrical organs.**—The electrical organs of many fishes (electric eel, torpedo) may be briefly noticed in this chapter. They consist of lobes of a honeycomb-like structure, usually developing in a similar way to muscle, and supplied freely with nerves which terminate in the cells of the honeycomb in expansions something like those of muscle end-plates; irritation of their nerves causes an electrical discharge. It appears that they may have become specialised and developed from ordinary voluntary muscle, for the sake of utilising the electrical current of action, and that the structural changes are associated with the development of this portion of the muscular mechanism at the expense of its strictly motor powers. The chemical examination of the electrical organ seems to show that the products of their activity are very similar to those of active muscle, CO_2 and an acid reaction being produced.

Du Bois Reymond showed long since that muscular contraction always yields a current which can be measured by a galvanometer, and Waller has lately shown a method of demonstrating in the human subject that there is an electric current produced by the heart's beat, and that it can be led off to a galvanometer by wires from the two hands. If it be the case that the peculiar powers of electric fishes have grown up from the electrical current of action common to all contracting muscle, it is difficult to trace the intermediate steps in the scale of development. The skate has an electrical organ in its tail which is not able to give strong shocks, although it can deflect a galvanometer.

181. **Magnetism.**—It seems to be rather doubtful whether any physiological effect has ever been observed to be due to the action of a magnet. Lord Crawford (then Lord Lindsay) and Mr. Cromwell F. Varley, with the help of an enormous electro-magnet belonging to the former, were unable to perceive any sensation even on placing their heads between its poles. But

in discussing these experiments in an address delivered at the Midland Institute at Birmingham,* in October, 1883, Sir William Thomson came to the conclusion that it is just possible that there may be a magnetic sense, and indeed a committee of the Society for Psychical Research,† who examined a large number of persons by placing their heads near the poles of an electro-magnet, found three who were sensitive and were able to say when the current was on or off. One of these persons was examined later by Prof. W. F. Barrett,‡ who found that when he was suffering from neuralgic pain it became intensified by the presence of a powerful magnet.

In some recent experiments conducted with very powerful electro-magnets by Dr. Peterson and Mr. Kennelly in Edison's Laboratory, the results were entirely negative, as the following extracts show. The subject placed his head between the poles of a large electro-magnet, which could be excited from a dynamo-machine. They reported as follows :—

"The armature of a dynamo was removed, leaving a space between the poles of its field magnet. This field magnet was then excited from another dynamo driven by steam power, and the subject introduced his head into the space between the poles. The weight of the electro-magnet was over 5,000 pounds, and the intensity of the magnetic field produced within the polar cavity after removal of the armature, though not uniform, may be estimated at a mean of 2,500 C.G.S. lines to the square centimetre. A long board was placed upon the base plate leading into this polar cavity, and the subject experimented upon lay on his back upon the board, with his head and shoulders in the cavity between the poles, and exposed thus to the full influence of the magnetic field. A switch, so nearly silent in action as to be inaudible to the subject, was arranged to close and open the exciting current circuit through the field coils. On closing the switch, nearly the full magnetic intensity would be active and permeating the head within practically one second. Similarly on opening the switch, almost the whole intensity would disappear in about one second.

"Five men, ourselves among the number, were subjected to trial. One case described will describe all.

* *Nature*, vol. xxix., p. 438.

† *Proc. Soc. Psychical Research*, part iii.

‡ *Nature*, vol. xxix., p. 476.

"The subject lay back upon the board, and concentrated his attention upon his sensations. His right wrist was extended and was grasped by one observer, who took sphygmographic tracings of the pulse. A second observer placed a hand on his chest to observe any irregularity that might occur in respiration. A third observer, in view of these two, but unseen by the subject of the experiment, opened and closed the switch that excited and released the field, signalling to the first two observers as he did so. The strong magnetic influence was, therefore, turned on or off at will, and without the knowledge of the subject. Several sphygmographic tracings were taken in each of our subjects, and in one the knee-jerk was tested continuously.

"The sphygmographic tracings taken during the *séance* show no change in regularity, in spite of the making and breaking of the enormous magnetic influence during its registration. The respirations were not changed in the least. The knee-jerk also presented absolutely no change. As to common sensations, there were none that could be attributed to the magnetic influence, and the subject could not discover when or whether the field had been excited. The testimony of all five subjects was alike.

"No change could be seen in the circulation in the web of a frog's foot when this was placed between the poles of a large electro-magnet, and no effect was perceptible in a dog which had been confined for five hours in a strong magnetic field."

Experiments were also tried with another magnetic arrangement, in which the magnetism was reversed 280 times a second, as follows:—

"A large coil of stout cotton-covered copper wire, about 30 cm. high, and 25 cm. internal diameter, composed of nearly 2,000 turns, and weighing about 70 kilogrammes, was supported horizontally in such a manner that the head of the subject experimented upon could be freely introduced within the coil, and subjected to the electro-magnetic field created there, by passing a current through the wire. The resistance of the coil was 10 ohms, and its inductance 0·73 henry. An alternating electromotive force of 1,200 volts, making 140 cycles, or 280 alternations to the second, was connected with this coil, the current supplied being 1·85 ampères. The magnetic field in the coil would thus be reversed 280 times to the second. Both of the authors acted as subjects in the experiments, permitting the 1,200 volt alternating current to be made and broken frequently

in the huge magnetic coil surrounding his head. No effect whatever was experienced. The coil itself hummed with the current, and a strip of sheet iron held in the cavity of the coil, but not touching it, vibrated perceptibly in the hand, and gave a distinct loud sound which was determined to be middle C of the musical scale.

"The authors conclude that the human organism is in no wise appreciably affected by the most powerful magnets known to modern science; that neither direct nor reversed magnetism exerts any perceptible influence upon the iron contained in the blood, upon the circulation, upon ciliary or protoplasmic movements, upon sensory or motor nerves, or upon the brain."*

It has recently been proposed to treat patients by bringing them close to the end of an electro-magnet which is suddenly excited and demagnetised by a mechanical interruptor, the idea being the generation of secondary currents in the patient's tissues by the rapid changes in the magnetic field.

It need hardly be pointed out that the phenomena of so-called "animal magnetism" have absolutely nothing to do with magnetism whatever. Moreover, the ordinary magnets used in medicine, and credited with wonderful powers, have a purely suggestive or psychic effect, and would, in all probability, be quite as useful if made of wood.

* Read before the American Electro-Therapeutical Association, 1892, reprinted with illustrations in the English *Electrical Review*, August 18, 1893.

CHAPTER X.

DIAGNOSIS.

Electrical testing. The motor points. Relation of spinal nerve-roots to muscles. Diagnosis charts. Changes in the electrical reactions. The reaction of degeneration. The sensory nerves. Nerves of the special senses. The auditory nerve.

182. **Electrical testing of nerves and muscles.**—The examination of the electrical reactions of the muscles is often of great assistance in the diagnosis of cases of paralysis. Even those who are indifferent to the therapeutic actions of electricity are accustomed to attach importance to the electrical reactions as an aid to diagnosis.

An electrical test often gives distinct evidence in cases where without it one could only guess at the morbid condition of the affected parts. The following history affords a useful instance of its value. A patient had an accident with broken glass, cutting himself in four places; as the ulnar nerve showed signs of injury the wounds were carefully examined. In two of them the nerve was found to be divided and was sutured. In the other two wounds the nerve could not be seen, and it was thought to have escaped injury at these points. No electrical test was made at the time. Some weeks later the patient was referred to the electrical department for examination as the limb remained paralysed. It was then found that the nerve had undoubtedly been divided in a third place, namely, in the uppermost wound, which was above the elbow. An operation was accordingly performed, the nerve was found to be divided and it was joined at that point. Some time later the case was tested again and the report was given that the nerve was in process of repair, and wanted only time and electrical treatment to recover its functions. After this the patient remained for some time with but slight signs of improvement, and a further exploratory incision was made to put aside all doubts as to the existence of re-union of the nerve. At the operation the electrical testing was vindicated by the discovery of a proper

re-union of the ends of the nerve. With time the patient made a good recovery. Another patient who complained of vague pains and weakness in the hand was shown by electrical testing to have a reaction of degeneration in certain intrinsic muscles of the hand, caused by division of the ulnar nerve in the centre of the palm by a wound from a spicule of glass which had penetrated from the wrist.

Electrical testing depends upon the fact that the normal reactions may become changed as a result of disease or injury. The last chapter dealt with the behaviour of nerve and muscle to the current of the induction coil, and to the make and break of a current from a battery or source of direct current, and in this chapter the changes due to disease will be considered, together with the practical details of testing. The changes looked for in the testing of nerve and muscle are changes in the visible responses given by the muscles. As there may be changes in the behaviour of the muscle both to the coil and the cells, both forms of electrical excitation are used in the examination of a muscle. The testing is usually done with the active electrode (§ 76) applied to the muscle itself, at or near its motor point. The testing electrode may also be applied to the nerve trunks, at a distance from the muscles, to determine their power of conducting motor impulses, their conductivity being shown by the movements of the muscles to which they are distributed; but it is to the muscles that the testing electrode is generally applied as the individual contractions of each muscle can be better seen in this way. Sensory nerves are also tested and their condition inferred from the responses of the patient.

In testing a muscle the electrodes required are the indifferent electrode (fig. 41) and the electrode handle with "closing" key (fig. 44). The former is to be placed over any convenient and remote part of the body, thus the patient may hold it against his chest, or it may be slipped down the back of the neck so as to be held in place by the pressure of the clothing, or, with a patient lying down it can be placed beneath the hips, or finally, if the patient is lying on his face it may be placed over the sacrum and held there by an assistant. In any case it must touch the skin with even and firm pressure throughout the process of testing. Both the electrodes and the surface of the body concerned must be well moistened with warm water or

salt and water, or weak sodium carbonate solution; and the more thoroughly this preliminary moistening is done the more satisfactory will the testing be. Salt and water lowers the resistance of the skin better than plain water, but has a greater tendency to corrode the electrodes.

In testing the intrinsic muscles of the hands and feet, and with a few other muscles, as for example the deltoid, it may be convenient to apply both electrodes to the skin over the part tested in such a way as to cause the current to pass right through the part, thus the interossei are most easily thrown into action with the indifferent electrode under the palm and the active electrode on the dorsal aspect of the hand.

Again for testing the muscles of the legs a very good position is for the patient to lie prone, with the indifferent electrode held by an assistant over the lumbar spine, the leg to be tested being flexed and supported vertically. In this position all the leg muscles can be reached easily, and the foot is free to move in any direction in response to the contractions of the muscles as they are tested.

The active electrode or testing electrode should be of small surface, one which is three-quarters of an inch in diameter is very suitable. Its surface may be slightly convex.

183. **The motor points.**—These are the points to which the testing electrode should be applied in order to set up a contraction most easily in the subjacent muscle, or they are points at which motor nerve trunks can be easily reached. They represent positions at which a maximum effect can be produced by a given current, and a good knowledge of the motor points enables one to carry out a test with comparatively weak currents, and therefore with the least amount of discomfort to the patient. Many diagrams of the motor points have been prepared, most of them being based upon von Ziemssen's plates (see Plates I.-VI. at the end of this volume).

Von Ziemssen prepared his plates by exploration of the surface with a testing electrode, and marking the points as they were found. He found by dissections on the dead body that the excitable points corresponded to points at which the main nerve supply entered the muscle.

It should be borne in mind that the motor points are not quite constant for different individuals, their exact places varying a little in different cases, but not so greatly as to diminish

the value of knowing their positions. In actual practice the best position of the electrode can be readily found by experiment, by moving it about in the neighbourhood of the usual position of the motor point of any particular muscle until the contraction shows that the exact spot has been touched. The ease with which the motor points can be found depends a great deal upon the amount of subcutaneous fat present, and the examination of the deeper muscles is much more difficult than of the superficial layer, indeed in the case of some of the deep muscles it is almost impossible to produce satisfactory evidence of a contraction limited to the muscle sought, for the diffusion of the current will throw into action the neighbouring superficial muscles and so obscure the result. It is very important to place the patient's limb in a good position, so that any muscular movement looked for may be readily seen; the muscles must be lax, the limb should be supported by the hand of the operator, and not lying flat upon the table or couch. It is best to begin with a current which is enough to throw the muscle into strong contraction and to apply it only for a very brief moment at a time, in this way the process of testing will be sooner over. It is well always to try the strength of the current on one's self before touching the patient.

It is assumed that the action of the individual muscles is known, so that when a contraction is produced, it can be referred to its proper muscle. The actions of the muscles were elaborately studied by Duchenne, and he has described them at great length in his "Physiologie des Mouvements." Besides watching for and seeing the movement produced by the contracting muscle, one may often save time by placing the hand over its tendon lightly so as to feel any movement, or one may see slight movements of the fibres of the muscle itself when they are too feeble to move the bone to which the muscle is attached.

The subjoined table of the points at which certain nerves may be conveniently stimulated will be of service, and Plates I.-VI., which show the motor points, must be continually referred to until they are known by heart. The areas of skin which are served by the several cutaneous nerves should also be studied. Heiberg's "Atlas of the Cutaneous Nerves," translated by Dr. Wagstaffe,* has some useful coloured outlines of these areas of distribution. Prof. Flower's "Atlas" may also be referred

* Baillière, Tindall and Cox.

to (see Plates VII.-IX., after Flower and Ranney). Brodie's "Anatomical Plates" are also useful for reference.

In order to profit by electrical testing it is absolutely necessary to know the anatomy of the muscles and their nerve-supply, also the distribution of the cutaneous sensory nerves. The relation of skin areas to the spinal nerve roots is also important.

Points favourable for the stimulation of nerve trunks.

In the upper limb :—

1. *The median*, along the inner border of biceps, and at the bend of the elbow.
2. *The ulnar*, in the groove between the internal condyle and the olecranon.
3. *The musculo-spiral*, at the point where it emerges from the triceps, namely, on the outer side of the upper arm about the junction of the middle and lower thirds.
4. *The musculo-cutaneous*, between the biceps and coraco-brachialis muscles.
5. *The long thoracic* (serratus magnus) on the inner wall of the axilla.
6. *The supra-clavicular point* of Erb. "At a spot one inch above the clavicle, and a little externally to the posterior border of the sterno-mastoid, immediately in front of the transverse process of the sixth cervical vertebra, a simultaneous contraction can be produced in the deltoid, biceps, coraco-brachialis, brachialis anticus and supinator longus." This is a motor point for the fifth and sixth cervical roots before they reach the brachial plexus.

In the lower limb :—

7. *The anterior crural*, in the fold of the groin just outside the femoral artery.
8. *The sciatic*, just below the gluteal fold at the back of the thigh.
9. *The internal popliteal nerve*, in the popliteal space, and to the inner side of the tendo Achillis.
10. *The peroneal nerve*, just above the head of the fibula, beside the biceps tendon.

In the face :—

11. *The facial*, through the cartilage of the lower surface of the meatus auditorius. Its chief ramifications can be reached

where they emerge from the parotid gland. Erb chooses for stimulation three main branches of the facial: (*a*) for muscles above palpebral aperture; (*b*) for muscles in front of upper jaw, between the orbit and the mouth; (*c*) for muscles of the lower jaw. He tests each of these in two places, first at points just in front of the ear, and secondly for (*a*) at the temple, for (*b*) at anterior extremity of zygomatic bone near its lower border, for (*c*) at the middle of the inferior border of the horizontal ramus of the lower jaw.

12. *The fifth*, at the supra-orbital foramen, at the infra-orbital foramen, at the foramen mentale, on the side of the tongue.

In the neck:—

13. *The spinal accessory*, at the top of the supra-clavicular triangle, where the nerve pierces the sterno-mastoid.
14. *The phrenic*, on the outer edge of the lower part of the sterno-mastoid.
15. *The hypoglossal*, along the upper border of the great cornu of the hyoid bone.
16. *The recurrent laryngeal*, along the outer border of the trachea.
17. *The pneumogastric* and *glosso-pharyngeal* along the track of the carotid artery just below the angle of the jaw.

184. **Relation of spinal nerve roots to muscles.**—Frequently it happens that paralysis affects a group of muscles; in these cases much light may be thrown upon the diagnosis, if it is possible to trace back the nerve supply of the affected muscles to their spinal roots. This is not always easy, particularly when the nerve trunks pass through a plexus like the brachial plexus, on their way from the cord to the muscles; for example, the distribution of a paralysis affecting some of the muscles of the hand might enable us to distinguish between a lesion of the trunk of the median nerve on the one hand, and a lesion of the first dorsal root on the other; in the latter case the whole of the thenar and hypothenar eminences, and all the lumbricales and interossei would be involved, in the former case many of these muscles would escape, namely, the hypothenar muscles, the interossei, the two inner lumbricales, the adductor pollicis, and the inner half of the flexor brevis, all of which are supplied by the ulnar nerve.

A paper published in *Brain*, 1894, by Dr. Allen Starr, gives a

tabular statement of the muscles represented in certain cervical segments of the spinal cord. As it is often likely to be of value in electrical diagnosis we reproduce it here in a slightly modified form.

Segments :—

4th cervical.—Diaphragm, levator anguli scapulæ, deltoid, rhomboids, spinati, biceps; supinator longus.

5th cervical.—Rhomboids, spinati, teres minor, deltoid, pectoralis major (clavicular portion), biceps; serratus magnus, supinator longus and brevis.

6th cervical.—Latissimus dorsi, pectoralis major, serratus magnus, pronators, biceps, triceps, brachialis anticus, extensors of wrist and fingers.

7th cervical.—Teres major, latissimus dorsi, subscapularis, pectoralis major and minor, triceps, flexors of wrist and fingers.

8th cervical.—Flexors of wrist and fingers, extensors of thumb, intrinsic muscles of hand.

1st dorsal.—Extensors of thumb, intrinsic muscles of hand (thenar, hypothenar, interossei).

For the lumbar enlargement Dr. de Watteville, *Lancet*, July 14, 1883, gives the following distribution :—

3rd lumbar.—Ilio-psoas, sartorius, adductors, extensor cruris.

4th lumbar.—Extensor femoris et cruris; peroneus longus; adductors.

5th lumbar.—Flexors and extensors of toes—tibial, sural, and peroneal muscles, extensors and rotators of thigh, hamstrings.

1st sacral.—Calf, hamstrings, long flexor of great toe, intrinsic muscles of foot.

2nd sacral.—Intrinsic muscles of foot.

Dr. Herringham* has also tabulated, as follows, the results of numerous dissections of the brachial plexus in new-born infants.

Usual nerve supply :—

3rd, 4th and 5th cervical.—Levator anguli scapulæ.

5th.—Rhomboids.

5th, or 5th and 6th cervical.—Supraspinatus, infraspinatus, teres minor.

5th and 6th cervical.—Subscapularis, deltoid, biceps, brachialis anticus.

* *Proc. Roy. Soc.*, March, 1866.

6th cervical.—Teres major, pronator radii teres, flexor carpi radialis. Supinator longus and brevis. Superficial thenar muscles.

5th, 6th and 7th cervical.—Serratus magnus.

6th or 7th cervical.—Extensores carpi radiales.

7th cervical.—Coraco-brachialis, latissimus dorsi, extensors at back of forearm, outer head of triceps.

7th and 8th cervical.—Inner head of triceps.

7th, 8th and 1st dorsal.—Flexor sublimis and profundus, flexor carpi ulnaris, flexor longus pollicis, and pronator quadratus.

8th cervical.—Long head of triceps, hypothenar muscles, interossei, deep thenar muscles.

The *pectoralis major* from 6th, 7th, 8th and 1st dorsal.

The *pectoralis minor* from 7th, 8th and 1st dorsal.

185. **Practical testing.**—When a fair degree of skill in finding the motor points has been acquired, the chief difficulties of testing the reactions of a patient's muscles will disappear. Nothing is so useful as to practice frequently upon one's own muscles, and the dislike which many people have to applying currents to their own persons is unreasonable, for a current which is strong enough to provoke contraction in healthy muscles is not really painful, and there is no way of learning the motor points like that of a practical experiment upon one's own muscles. Half an hour spent in picking out one's own motor points, and in observing the relative sensitiveness of the skin in different parts of the body, and in noting the effect of a thorough moistening of the skin before applying the testing current will well repay a beginner in electrical testing.

Another small point of importance is to make it a rule always to apply the current to one's self at the commencement of a test. If this is done the patient feels reassured, and the chance of the current being applied too strongly is decidedly lessened. The easiest method is as follows:—

Place the indifferent electrode in position on the patient and moisten the skin of the part to be tested, then grasp that part with one hand, and, taking the testing electrode in the other apply it to the back of the hand which is holding the patient, then, on closing the key the current will pass from operator to patient through the hand of the operator, who will be able to judge of the strength of the current by the sensation of the muscular contraction produced, and will be able to adjust it

accordingly. Always commence testing with the induction coil, and finish with the cells. There is no need to use very strong coil currents. If the muscles do not react to coil currents of moderate strength, they are not likely to do so with severely strong currents.

When testing with the battery current begin with about sixteen cells for the limbs, or half that number for the face, the testing electrode should be made the kathode. Note whether a closing contraction is visible, and if none is seen increase the number of cells in circuit until it appears, and take readings of the galvanometer; when the first closing contraction becomes visible note the effect of moving the electrode, look for the most effective spot for stimulating the muscle, then compare the ACC with KCC, and take especial notice of the nature of the contraction to see whether it be quick or sluggish, and compare the contractions obtained by direct stimulation of the muscle with the effect of stimulating it indirectly through the nerve trunk. Lastly, test sensation with the induction coil current, and note the results upon a table like that given on the accompanying page, to form a report for the use of the medical man who has referred the case for testing.

Compare the reactions of the healthy side with those of the affected side.

When the affected parts can be compared with the corresponding region on the opposite and sound side of the body, it is not difficult to perceive changes in the electrical reactions. When the disease is bilateral this is not so simple, and one must depend to a certain extent upon previous experience, and upon comparisons with one's own reactions; but, wherever possible the comparison of the affected muscles with their fellows of the opposite side of the body is a matter of the first importance.

186. **Changes in the electrical reactions.**—The changes which may be found in the reactions as the result of disease or injury are classified as follows:—

1. Quantitative changes or changes in the amount or quantity of response to stimuli, the character or quality of the reactions not being otherwise changed.

This includes simple increase of excitability and simple decrease of excitability to coil and cells, changes which are usually spoken of as *quantitative* changes.

Report of Electrical Reactions.

Name—T. B. S. *Age*—32. *Date*—Oct. 4, 1894.

Region examined—Left arm and forearm. *Diagnosis*—Neuritis of musculo-spiral Nerve.

Muscles.	Induction Coil.	Battery.	Excitability.	Remarks.
Triceps	Natural.	Natural.	Natural.	A tender point over musculo-spiral trunk in middle of upper arm.
Supinator longus	Decreased but not lost.	Sluggish.	Increased.	
Ext. carpi rad. longior	,,	,,	,,	Injury three weeks before.
,, ,, ,, *brevior*	,,	,,	,,	Partial reaction of degeneration in all these muscles except triceps.
,, ,, *ulnaris*	,,	,,	,,	
,, *comm. digit.*	,,	,,	,,	*Supinator brevis* not tested.
,, *ossis metacarpi poll.*	,,	,,	,,	
,, *primi internod. poll.*	,,	,,	,,	Sensation impaired over extensor aspect of forearm.
,, *secundi internod. poll.*	,,	,,	,,	
,, *indicis*	,,	,,	,,	Voluntary power much impaired. Wrist drop.
,, *minimi digiti*	,,	,,	,,	The other muscles of the limb quite normal.

Treatment advised—(Electricity and massage). *Prognosis*—Favourable.

2. Qualitative changes or changes in the nature or quality of the reactions. These include the reaction of degeneration, both complete and partial, the myotonic reaction, &c.
3. The condition of total loss of all visible contractions, both to coil and to cells, must also be considered.

187. **Quantitative changes.**—In unilateral disease increased or decreased excitability is shown by differences in the behaviour of the two sides. If the normal side be used as a standard for purposes of comparison an increase of excitability will be inferred if the minimal contraction shows itself with a lesser current on the affected side. If both sides are affected, then an increased excitability may be inferred if the minimal contraction is seen with currents which are weaker than those which the the operator has learnt to recognise as usual in healthy people.

The recognition of increased or decreased irritability is easy when the increase or decrease is considerable, but to diagnose slight increase or slight decrease demands great care, as there are many disturbing factors to be guarded against. With the battery current, a careful attention to galvanometer readings is the best guide, but even then one has to consider the differences which may depend upon the place of the testing electrode, for a slight movement away from the motor point will make the current less effective, and so will simulate a decrease of irritability. Again unequal pressure of the electrode, when comparing two points, may cause an apparent difference in irritability, for with increased pressure the electrode is pushed nearer to the nerve or muscle, and is rendered more effective. The resistance of the skin may also vary during a test, and as it usually falls while the testing is in progress, this may complicate matters. With induction coil testing there is no galvanometric means of checking off the strength of the currents employed, and one has to fall back upon comparisons of the voltage in the ways indicated in § 61. This leaves an opening for errors due to differences in resistance. Sometimes the skin resistance in a paralysed limb is much increased, through alterations in the condition of the skin which covers it. Consequently when there is a question of carefully determining small decreases or increases of irritability, measurements of the resistance must first be taken as carefully as possible with the battery and milliamperemeter, and the situation of the electrode upon the skin must be carefully marked.

The diagnostic value of small quantitative changes is not very great, so happily their determination is not of the first importance.

Increased irritability occurs usually in those conditions in which increased reflexes are found. Both signify increase of irritability in the central nervous system. It is observed in chronic myelitis, in degeneration of the lateral columns, and in hemiplegia, also in tetany, in which disease it becomes a prominent feature.

Diminished irritability occurs in many diseases. It is seen in the milder forms of those injuries and diseases which show qualitative changes when they are more severe, for example, in acute anterior poliomyelitis a reaction of degeneration will be found in some of the paralysed muscles, while others will only show simple decrease of irritability. In neuritis, too, both traumatic and other, one may see either qualitative or quantitative changes, according as the attack is severe or mild.

Simple fatigue may cause decreased irritability. In myasthenia gravis, decreased irritability, coming on during the progress of the testing, is a striking symptom. A decrease in the response to a series of stimuli may often be noted in muscles whose reactions are quantitatively reduced.

The electrical properties of the testing circuit have also a decided influence upon the apparent excitability of nerve and muscle, and this introduces fresh disturbing factors when the results of testing with one apparatus are compared with those of a different one. Dubois* has shown that the presence of resistances in the testing circuit lowers the stimulating effect of a current of given magnitude, thus a current of three milliampères passing through a circuit composed of the body and of a resistance, is less effective in causing a muscular contraction than a current of three milliampères traversing the body in a circuit without any other external resistance, and he further goes on to prove that this effect is due to the self-induction of the testing circuit, and that it tends to lower the stimulating effect of the current by retarding the rate of growth of the current at the moment of closure, which is the moment also of testing. Thus a stimulus is effective in proportion to the suddenness with which the current rises to its maximum, and the greater the self-induction of the circuit, the slower this rise

* *Arch. d'électricité médicale*, 1898, page 1.

becomes. The presence in the circuit of a milliamperemeter, which is an instrument of high self-induction, will therefore tend to increase the magnitude of the current required to cause contraction in the muscles, and this will be most marked with galvanometers wound with many turns of wire. By shunting the galvanometer (§ 83), or by the use of a condenser connected in shunt to the galvanometer terminals, the testing current may be made more effective, and the minimal contractions obtained with smaller currents. The self-induction of resistances may also influence the results in testing with coil currents.

188. **Qualitative changes—The reaction of degeneration.**—This term was introduced by Erb to signify the combination of altered electrical reactions, which occurs in the nerves and muscles under certain definite morbid conditions, the peculiar feature being that the change is a qualitative one; that is to say, there is an alteration in the quality of the response which the muscles make to the battery current. The kathodal closure contraction may become relatively less easily elicited than the anodal closure contraction, though this is not invariably the case, but the contraction provoked is a slow and sluggish one, differing greatly in its character and appearance from the instantaneous twitch given by a normal healthy muscle.

This reaction of degeneration (usually symbolised by the abbreviation RD) is of very great importance. Its discovery and development arose from an observation of Baierlacher in 1859, that the muscles in a case of facial paralysis did not respond to the currents of the induction coil, but reacted with unusual force to the battery current. To Erb's careful study of the phenomena, then first made known, we owe the most important fact connected with electricity in medical diagnosis.

The investigation of the reaction of degeneration has been pursued both clinically and experimentally, and its value consists in the fact that when it is present we can diagnose a break in the nervous link which connects the end plate of the muscle with its nucleus of origin in the grey matter of the anterior cornu of the spinal cord. A lesion causing the reaction of degeneration must be situated in the grey matter of the anterior horn in the cells from which the nerve fibre starts, or else somewhere in the course of the nerve fibres passing from there to the muscle. The reaction of degeneration does not follow central nerve lesions which are wholly above the spinal ganglion cell

whence the nerve fibre springs, nor does it follow affections which are confined to the muscle fibres proper (idiopathic muscular atrophies).

In RD the irritability of the nerve disappears entirely, and therefore stimulation of it, whether by coil or by cells, has no effect; the muscle on the other hand retains its irritability to the battery current, but not to the coil current, that is to say, the muscular irritability is still present for certain stimuli. Though it does not react to the interrupted current of an induction coil, it can react to a mechanical shock, or to a battery current slowly made and broken. If the battery current be made and broken rapidly by a mechanical interruptor, the muscle may not respond at all, or it may respond once by a single slow twitch at the first closing of the circuit. As a curarised muscle will still react to coil currents, though not so readily as a normal muscle, the loss of irritability to coil currents seen in a muscle with the reaction of degeneration signifies something more than a failure of the intra-muscular nerve endings, and it probably means that a trophic change has occurred in the muscle protoplasm, and the production of ACC more easily than KCC is a further evidence of the change which has occurred. This alteration of the relative effect of the poles is not an essential part of the reaction of degeneration, for it is not constantly present. Many observers describe this "polar change" as an invariable concomitant of the reaction of degeneration, but it is not sufficiently constant to have a diagnostic value of prime importance. Another important alteration is that the irritability of the muscle to the battery current may be greater than in health, strong contractions being set up in the affected muscles by currents which are too weak to produce any visible movement in neighbouring healthy muscles.

It is only in fairly recent cases that the phase of exaltation of muscular irritability is manifested, and in most cases of RD of long standing, a progressive decrease of irritability in the affected muscles is seen in the later stages.

Erb's definition of the reaction of degeneration is the following:—"It is characterised by the diminution and loss of 'faradic' excitability in both nerves and muscles, whilst the 'galvanic' excitability of the latter remains unimpaired, is sometimes notably increased, and always undergoes definite qualitative modifications."

189. **The course of the reaction of degeneration.**—After the onset of the lesion there will be in the nerve a transient period of increased irritability, followed by a progressive decrease, and at the end of a week or ten days the irritability of the nerve will be completely abolished, and will remain so unless recovery takes place.

In the muscle the reactions at first run the same course as in the nerve, the decrease of irritability to coil currents goes on to complete disappearance, and by the end of a week the response to battery currents begins to show an increase of excitability, with sluggishness of contraction, and sometimes with ACC > KCC. After a variable period of time, the motor point loses its importance for testing purposes, and it will be found that a better contraction is elicited with the testing electrode at the distal end of the muscle, than at the motor point. This effect has been described by Doumer as the "longitudinal reaction." By comparing the relative forces of a contraction with the electrode at the motor point in one case, and at the distal part of the muscle in the other, it is possible to form an opinion as to the degree of degeneration of the intra-muscular branches of the nerve. The longitudinal reaction is produced by direct stimulation of the muscular fibres, the reaction at the motor point by stimulation of the muscle through its nerves.

After six or eight weeks diminution of excitability sets in, and if recovery is not to take place the diminution is progressive, until at last contractility may disappear entirely.

In cases which recover, it usually happens that the power of voluntary movement will return some little time before the response to electrical stimuli. A slight response to coil currents is the first sign of improvement to be noticed, and this will be noted when the response to the battery currents is still sluggish and feeble. Sometimes the muscle will show a slight coil reaction, when stimulated through its nerve trunk, before it responds to a similar stimulus applied directly to the muscular fibres.

Such is a review of the typical electrical reactions of nerve and muscle after complete severance of a nerve, and these reactions modified in various ways, by the amount of destruction to the motor centres, or the conducting nerve fibres, are characteristic of the several nervous diseases where qualitative changes in the electrical reactions are to be observed.

Professor Erb has pointed out that deviations from the typical form of the reaction of degeneration may be met with. He says: "You must not expect to find in every pathological condition so great a uniformity in the course of these modifications as is to be met with in experiment, or in a simple traumatic lesion of the nerves. This does not often occur in disease, where many deviations may be caused by the nature of the injury, different affections of trophic influences, occasional improvement, or new elements of disturbance following one upon another; and one is not warranted in concluding from some irregularity, such as presents itself in long-standing cases, that one has discovered some fresh anomaly. The time at which repair takes place determines great differences in the general manifestation of the reaction of degeneration. If this happens early, the nerve may be endowed with galvanic and faradic excitability while the changes in the muscle are at their height. The latter cannot be reformed so quickly, and require for the purpose some lapse of time. It may happen then, that when the nerve is excited, the muscle responds with normal contractions, but still when stimulated directly, exhibits the reaction of degeneration. But if repair sets in very late, it may be that the muscular excitability is already greatly diminished when the excitability of the nerve begins to be slowly restored. There is, therefore, an indefinite number of special cases, which nevertheless may be mastered by carefully attending to the conditions of time and other circumstances."

190. **Partial reaction of degeneration.**—This term is applied to cases in which some degree of contractility for coil currents is present, although there is decided sluggishness of contraction of the muscle for the battery current.

The existence of "partial RD" makes it important in testing, always to confirm the results of the coil test by the application of the battery current test. If partial RD be present, there is usually a perceptible alteration in the coil reactions, but this may be overlooked, and, in that case, conclusions drawn from the presence of coil reactions alone would seriously mislead. Between partial RD and complete RD there are various degrees of alteration.

The degree of sluggishness of a contraction may vary within wide limits, the reaction to the coil may be very faint or fairly strong. It has been suggested that partial RD represents a

changing state of the nerve or muscle, and that a change to complete RD on the one hand, or to a normal reaction on the other, may be looked for in cases showing partial RD.

191. **Conditions which lead to the reaction of degeneration.**—Briefly speaking, RD follows damage in that region of the motor path to which Dr. Gowers has given the name of the "lower segment," that is to say, that part of the course of a motor fibre which commences at the motor ganglion cell of the nucleus of origin, or of the anterior cornu, and is continued down as a nerve fibre to the motor end-plate beneath the sarcolemma of its muscle. It does not follow damage limited to the "upper segment," and in the lower segment a certain degree of severity in the damage is necessary to produce it. RD is found after division, destruction, or injury of motor nerve trunks, and after disease or injury affecting the ganglion cells of the anterior cornu of the cord, or the corresponding nuclei of origin in the case of the cranial nerves. Under one or other of these morbid states can be grouped pressure palsies of all kinds, division or laceration of nerves, different forms of peripheral neuritis, poliomyelitis anterior, both acute and chronic, muscular atrophies from disease in the spinal cord, or in the nerves (but not atrophies of muscular origin), also acute and chronic myelitis, lead poisoning, and diphtheritic paralysis. The reaction of degeneration is not found in the paralysis of cerebral disease, except when the implication of the nuclei of origin, or of the nerve trunks of the cranial motor nerves, produces a reaction of degeneration in the muscles which they supply, nor does it occur in diseases limited to the white matter of the cord, nor in hysterical paralysis.

192. **Prognosis in the reaction of degeneration.**—"Other things"—that is the cause and nature of the disease—"being the same, the lesion is serious, the probable duration of the disease longer, the definite prospect of a cure more remote in proportion as the reaction of degeneration is developed and complete, and in proportion to the stage which it has reached" (Erb).

He instances the value of the symptom in the prognosis of simple facial palsy, distinguishing three forms:—(1) *Mild*, electrical reactions normal, prognosis favourable, probable duration three weeks. (2) *Intermediate*, partial RD, duration one or two months. (3) *Serious*, complete RD, prognosis bad, duration three, six, nine months or longer.

At the same time he emphasizes the importance of the saving clause with which the quotation opens, insisting that it is not permitted to reason alike in all paralyses, without giving due weight to the importance of the lesion producing them, for instance, the prospects of a case of facial palsy from caries of the petrous portion of the temporal bone cannot be expected to resemble those where the mischief has been set up by a mere exposure to cold; and electrical reactions which are a guide to prognosis in cases of the latter type must not be forced into a similar interpretation for the former. There is an important remark of Dr. de Watteville's which may be quoted:—"It may not be unnecessary to guard the student against the error of looking upon the occurrence of alterations in the response of nerves and muscles as in itself indicative of irreparable mischief. On the contrary, RD is often of far more favourable prognosis than normal reactions, which we have already found to be consistent with absolutely incurable lesions, involving complete paralysis. Intractable spasms, tremors, or convulsions again are never accompanied by any notable disturbance, quantitative nor qualitative, of the electrical reactions."

To this may be added that the electrical test can only give information as to a certain portion of the nervous system, namely the lower segment, and if inferences are to be drawn from the observations made, it will be necessary for the observer to take many other circumstances into consideration, in order to draw the correct inferences from his facts.

Among the practical points which continually arise in connection with the RD, perhaps none are more important than the giving of an answer to the question whether a nerve trunk is divided or only hurt. The question is one of the utmost importance, because the whole future conduct of the case rests upon the answer, and it may be difficult to answer it because RD will equally follow division and severe injury. Perhaps it will be useful to consider an actual case:—A barber on board ship was at work with a pair of scissors when the vessel gave a heavy roll and the patient accidentally plunged the scissors into his armpit. It bled a good deal and was bandaged up tightly and remained so for several days until the ship came into port. He was then found to have an extensive paralysis of the forearm and traumatic aneurysm of the axilla. I was asked to report on the paralysis and to state whether any nerves were divided or

not. He showed RD in the ulnar and musculo-spiral areas. In the latter area one muscle, the triceps, did not show complete RD, for it retained its contractility to the coil in part, while in the ulnar area the paralysis was not absolute, the wasting was not extreme and sensation though impaired was not altogether lost. On these grounds the report was given that the musculo-spiral nerve was not severed, and that in all probability the ulnar had also escaped. His nerve trunks accordingly were not surgically explored, and under treatment by electricity he made a gradual but complete recovery. His paralysis probably had been caused by the tight bandaging and not by the punctured wound.

Another case was one of gunshot wound of the lower half of the arm with extensor paralysis. He was examined electrically about seven weeks after the accident when healing of the extensive lacerated wound had made good progress. There was RD of all the extensors, but wasting was not extreme, the contractions were of very good volume and the sluggishness was not conspicuous. Judging that if the nerve had been completely severed the reaction of degeneration would have begun to enter the stage of decreased irritability, and finding it to be not decreased an opinion was given that the trunk of the musculo-spiral had escaped. The later history of the case proved this opinion to have been correct.

Thus the diagnosis between severance of a nerve and serious injury without severance cannot be made with certainty by electrical testing, although a careful scrutiny of all the phenomena, motor, sensory, vasomotor and trophic will usually enable one to form a correct opinion.

Anything incomplete in the degree of paralysis, of anæsthesia, and of wasting, points to a non-severed nerve, and the progress of the symptoms when the case is watched for a time will also throw light upon the question. In cases of total division the reactions rapidly become degraded, and the other symptoms become worse, while in cases of injury without division the patient will show slight improvement, chiefly sensory, from week to week, and the reactions will not change quickly for the worse.

Another common problem in practical testing is the following :—A nerve-trunk has been operated on and sutured ; after the lapse of a certain period of time the case is sent for a report

as to whether the sutured ends have become united, the patient being anxious owing to there being no return of voluntary power. Here, again, the mere testing of the muscles does not help much. Even in favourable cases the reaction of degeneration may show a general degradation in character for a time even when sensation is beginning to return.

After operations for suture of divided nerves the chief need on the part of patient and surgeon is patience. After division of a nerve recovery is slow, especially if an interval has passed between division and re-union; reactions of normal quality are slow to reappear, particularly when there is a long stretch of nerve between the wound and the muscle tested; the most distal muscles suffer the most, and regain power and reactions the latest.

In the simplest cases of division followed by immediate successful suture a considerable time must elapse before any return of voluntary power can be recognised in the paralysed muscles. Three months may be considered a short time to wait. A return of sensation can be detected earlier, the return of induction coil contractions comes later. In these favourable cases the sluggish contraction to cells will continue to be present, and to be fairly strong throughout. If an interval of time passes between the division of the nerve and the operation for suture, the reaction will probably have undergone some decrease in strength, and may even have disappeared, at the time of the operation for suturing.

If this has happened recovery will be very slow, and the appearance of a sluggish RD contraction may be the first sign of returning activity.

Those who are familiar with electrical testing are well aware of the fact that notable variations in degree are to be seen in the reaction of degeneration. Some of these are certainly due to a general degradation of the state of the muscle in cases of long standing, which makes the contractions more difficult to see, and deprives them of some of the sharpness of character which one might expect. Examples of this kind in which the RD can still be observed but which are not good cases for the demonstration of typical RD are common enough. The polar change with predominance of ACC over KCC is referred to by Professor Erb as one of the most constant phenomena in medicine, but in my experience and in that of others the phenomenon

is so inconstant a part of the reaction of degeneration as to be without diagnostic value. It is possible that the relative order of appearance of ACC and KCC may be influenced by chance positions of the testing electrode. See fig. 108 for the virtual polarity of parts around an electrode. Thus a positive electrode near to a motor point but not exactly over it might set up a virtual negative polarity at the motor point and *vice versâ*. Again, the degree of sluggishness, or in other words, the duration of the contraction produced in muscles by the closure of the current from the cells varies within a wide range; so that at times one may see a contraction so long and slow as to resemble a veritable peristalsis of unstriped muscle, while in other cases it is only after a careful comparison with sound muscles that one can at last determine whether the contraction to cells is or is not slow. The "longitudinal reaction" is often of service in deciding a doubtful question of the quality of a contraction (§ 189).

193. **Recent work on electrical reactions.**—During the last few years there has been a great deal of work done in connection with the testing of muscle and nerve. Mendelssohn has applied the graphic method to the study of muscle curves in the living subject, and has described certain modifications in the form of the tracings under the names of spastic, paralytic, atrophic, and degenerative curves. These are interesting, but are not yet of any great diagnostic utility. The apparatus used is a combination of key electrode with a tambour for receiving the impulse of the contracting muscle and transmitting it to a revolving drum. It was described by Radiguet and is made by Ch. Verdin, 7 Rue Linné, Paris.

Rich has described a variety of polar change in which the KOC contraction appears readily. This is suspected in testing with moderate currents and using the kathode, if an opening contraction is produced in addition to the ordinary closing contraction.

The ready production of duration tetanus (§ 166) is sometimes observed. It is connected with the reaction of degeneration, and may be confounded with it. The myotonic contraction is something analogous. It occurs in Thomsen's disease, and rarely, in a few other conditions.

It is quite likely that with increased knowledge of electrical reactions it may become possible to establish differences between the reactions of a case with a divided nerve and those

associated with less serious injury. Hitherto nerve and muscle have been examined by means of coil currents and battery currents. When more is known of the effect of condenser discharges and of the effect of battery currents of various durations and rates of interruption it is probable that the reaction of degeneration may become split up into several divisions.

194. **Sensory nerves.**—There is but little to be said on the subject of alterations in the electrical reactions of sensory nerves. Simple increase of sensibility and simple decrease of sensibility can be detected, and apparently the degree of electrical sensibility corresponds rather with the degree of perception of pain than with that of perception of tactile sensations. This has been determined in diseases in which these two forms of sensibility are often affected in unequal degrees.

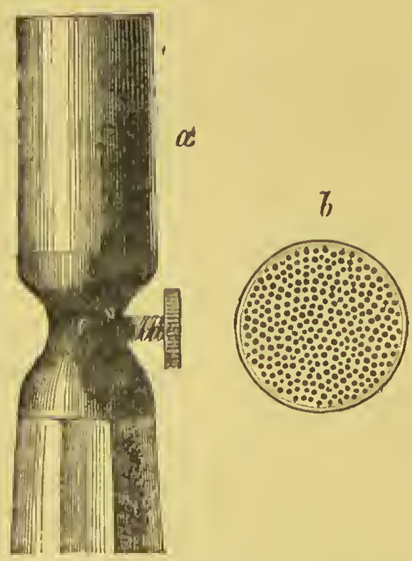


FIG. 111.—Cutaneous testing electrode. *a.* Side view. *b.* End view.

For investigating the electro-cutaneous sensibility, the interrupted current must be employed, and it is as important to compare the affected with the sound side, and to take into consideration the amount of skin resistance, as it is in examining the muscles. For accurate work the resistances should be measured with a battery and a suitable galvanometer. For simpler testing the sledge coil must be used, and the distance of secondary coil from primary must be noted and recorded. For testing the sensibility of the cutaneous nerves, one may use

a metallic brush for the active electrode, and should not moisten the surface of the skin ; or an electrode devised by Erb may be used. It consists of a bundle of 400 metallic wires insulated from one another at their distal ends, and enclosed in a tube or ring of vulcanite. At one end the wires are all put in metallic communication, and are attached to an ordinary testing electrode handle, the other end is polished, so that when applied to the skin it has the effect of a smooth surface. It covers an area of skin of about two centimetres in diameter, and into this the current enters in 400 parts from the ends of the individual wires. Thus a simultaneous action on numerous nerve terminations is secured, and with the interrupted current the degree of stimulus may be estimated for the first appearance of sensation, and for the first perception of pain.

An ingenious method of testing the sensibility of a patient is to use the finger-tips as the electrode, for by proceeding in this way, the operator can use his own sensations as a guide, and can check the patient's statements by his own feelings. An opening and closing key, kept out of the patient's view, can be included in the circuit if deception is suspected. If a systematic examination of the different parts of the body is made, with a finger-tip for electrode, it will show how greatly the sensibility varies in different regions. To do this, one electrode is applied to the patient, and one to the operator, the circuit will then be closed when the operator places his finger on the patient. The operator then feels the current which is passing to the patient, and can judge from his own sensations of the degree of sensibility possessed by the patient.

195. **Nerves of special senses.**—*The auditory nerve.*—Of the nerves of special sense, there is one which may be usefully tested, namely, the auditory, because of the changes which occur in its irritability in *tinnitus aurium.* We have already pointed out that in health it is possible to obtain reactions when a battery current passes through the auditory nerve, and that like the motor nerves, the auditory responds more readily to kathodal than to anodal stimulation, and generally exhibits the same electrical reactions, the response being the production of a subjective sensation of sound ; but in certain cases the auditory nerve answers to electrical currents more readily than it does in health. In these cases it is supposed that there is a state of hyperæsthesia, or of irritation in the nerve, and that the

tinnitus is really the expression of that irritable state. In some cases of tinnitus, the kathodal closure increases the sounds so long as the current is flowing, while the anode (anodal closure) diminishes or abolishes the sound during the passage of the current.

The auditory nerve can best be tested or stimulated by a bifurcated electrode, which can be applied to both ears at once. By proceeding in this way there is less likelihood of making the patient giddy (§ 174). A binaural stethoscope may be used, if

Fig. 112.—Aural electrode.

pads of moistened sponge are substituted for the ivory ear pieces; these ends are to be applied just in front of the tragus, and kept in place by an elastic band or spring.* If a stethoscope is used as a temporary expedient, the lower portion should be removed, and the tubes closed up by small corks, the wire from the battery is fastened securely to the metal, and the other electrode may be applied to the sternum or back. When one ear is to be tried at a time, only one of the sides of the binaural electrode is moistened.

* Messrs. Arnold and Son can supply this electrode.

CHAPTER XI.

General Therapeutics.

Effects of electricity. Choice of current. Strength of current. Choice of pole. Methods. "General faradisation." Central galvanisation. Disorders of nutrition. Anæmia. Rickets. Gout and rheumatism. Diabetes.

196. **Effects of electrical treatment.**—In the application of electricity to medical treatment, the first questions to arise are the following:—(1) What effects may be expected from the electrical applications? (2) What form of current is to be employed? (3) What strength of current is to be applied, and for how long? (4) What is to be the direction of the current, and which pole is to be applied to the affected part? (5) What are the manipulations required?

The effects produced by electrical treatment may be arranged thus:—

(*a*) *Stimulating and trophic effects.*—Electricity acts as a stimulus, not only to the contractile tissues, both directly and through their motor nerves, but also upon the sensory nerves, and through them upon the central nervous system. It also influences the vaso-motor system. The vaso-motor influences play an important part in the relief of the pain and congestion which occur in so many morbid states. A very large part of the good effects of electricity in disease, is to be ascribed to the stimulation which electrical applications produce.

All living tissues are stimulated to greater activity by electrical currents, particularly when the currents are variable. D'Arsonval has shown that under the action of a varying current the metabolic processes of the body are increased, even if there be no muscular contraction set up, so that the effect is not merely secondary to the muscular contractions produced by the treatment (§ 176).

The improvement in health shown by rickety children, and by anæmic and debilitated persons when they are treated by general electrisation with alternating or interrupted currents

is conspicuous; they increase in weight, they become rosy cheeked, and they eat and sleep better.

These effects are to a certain extent shared by other modes of stimulation, as for instance, by massage, by hot and cold douches, and so forth; but electricity has certain advantages over these other modes of stimulation, from its greater power of setting up active muscular contractions, and from the ease with which it can be directed and regulated as to strength.

The effects which peripheral stimulation exerts upon the central organs, and through them upon the periphery again, may play an important part in electrical treatment, and afford an explanation of the benefits which follow in cases, as for example, of hemiplegia and of infantile paralysis, where the treatment has been applied to the peripheral parts only.

(*b*). *Electrotonic effects.*—Physiological effects of electrotonus have been used as a guide in treatment. With alternating or interrupted currents electrotonic states cannot be expected, but with constant currents the phenomena of electrotonus may be kept in mind in treatment, for they show when the exciting action of the exalted irritability of kathelectrotonus is to be brought to bear upon a part, as in paralysis; and when the calming effects of the diminished irritability of anelectrotonus are more desirable, as for the relief of pain and spasm. It is difficult to assess the value of electrotonus in electrical treatment (§ 165).

(*c*). *Electrolytic effects.*—The changes produced by electrolysis are most manifest at the surfaces in contact with the electrodes. In general medical treatment these immediate electrolytic effects are undesirable, as they tend to cause injurious chemical action upon the skin, and they are therefore guarded against by interposing some moist material between the metal of the electrodes and the surface of the body (§ 161). In surgery the destruction of tissue by means of electrolysis is used for the cure of nævi, for the removal of superfluous hairs and moles, and for other purposes, and it will be dealt with in a separate chapter.

In addition to the electrolytic action at the region of the poles, there is also an interpolar action, due to ionic migrations and interchanges which take place in the tissues along the whole line between the poles; the effects of these interpolar changes have only quite recently received due examination by Leduc. They may justly be considered as producing some of

the "trophic" or "alterative" effects which follow electrical treatment. The importance of the ionic movements must be borne in mind, and may hereafter influence the choice of the metal of the electrodes and the liquids used to moisten them.

(*d*). *Osmotic effects.*—These have been considered in the chapter on physiology (§ 162) and are probably subordinate to the electrolytic transport of ions, and the molecular changes induced thereby.

197. **Choice of method.**—A very large part of the benefits derived from electrical applications can be ranged under the heading of stimulation, and generally speaking it may be said that for stimulation, pure and simple, variable currents must be used. The induction coil should therefore be chosen for the treatment of paralysed muscles if they are able to react to it, but if they present the reaction of degeneration, and have lost their irritability for coil currents, then the constant current may have some advantages. Fashion has had much to do with determining the choice between the two modes of treatment.

Duchenne was a firm believer in the superiority of the induction coil for the treatment of all kinds of paralytic conditions, and Remak was as warm a supporter of the constant current. The former writer declared that he had met with far better results from the interrupted than from the constant current. The latter was as confident of the superiority of his method.

Electrolytic or electrotonic effects are probably possessed by direct currents alone; stimulation, direct and reflex, vasomotor and trophic effects are better produced by varying or alternating currents, and as these effects form so large a part of what is desired in cases coming for electrical treatment, the induction coil is the instrument most commonly used in the majority of cases.

The direct current of the battery has been preferred to the coil for the treatment of muscles which show the reaction of degeneration. The reason given for this is that the battery current will make such muscles contract when the induction coil can no longer do so. If the visible contraction of the muscle were the measure of the good done to it by the treatment, the reason would be a valid one, but that this is so is rather an assumption than a proved fact. I have treated large numbers of cases of paralysis with RD by interrupted currents, and have obtained very good results in that way, and I consider

that it is at least as useful as the direct current for all kinds of paralysis. When direct current is used, and the electrode is moved over the surface of any part in the usual way, the effect obtained is that of a varying current applied in succession to the different parts touched by the electrode, and the difference from an induction coil current is chiefly in the rate of variation.

In order to determine whether the direct current of a battery is better than that of an induction coil for treating cases of paralysis, a long series of comparable cases must be treated by each method, and the results examined. I have been able to do this in the electrical department at St. Bartholomew's Hospital to a considerable extent, and I am satisfied that good results can be obtained with both methods. As it is probable that the effects of the two methods do not exactly coincide, it seems reasonable to make use of both kinds of application and to treat muscles showing RD, by an application both from direct current and from the induction coil alternately.

In conditions other than paralysis the battery current may be far superior to the coil. Coil currents, from their rapid variation, may be too sharply stimulating, and they may affect the cutaneous sensory nerves too much; they may not penetrate deeply enough, they may be unsuitable in other ways, as for example for influencing unstriped muscle, if vaso-motor effects are desired, or the intestinal or bladder muscle is to be treated. For the relief of pain direct current is the best. Some pains may be relieved by the induction coil current acting painfully as a counter-irritant, but in general the pains of neuritis and neuralgia are unfavourably influenced by rapidly varying currents. With the battery current the intensity of stimulation can be controlled by regulating the rate of change of current. A steady flow with the electrodes held still (stabile applications) is the least stimulating to nerves and striped muscle; if the active electrode is slowly moved over the part (labile application) stimulation is rather greater, and it becomes much greater with sudden makes and breaks of current, while finally the strongest stimulation is produced by sudden reversals. Considerations like these determine the choice of cells or coil for the different purposes of treatment, and in the succeeding paragraphs which consider electrical treatment in detail further precise indications will be found.

198. **Strength of current.**—In determining the strength of current, it is necessary to remember that no needless pain should be inflicted upon the patient. With the coil the operator must gauge the strength of his current upon himself first, and must repeat the test with every increase in its strength; a strict adherence to this rule is the best plan, by far, of ensuring the proper amount of caution. Patients, as a rule, are extremely intolerant of painful shocks, and it must be remembered that the very name of electricity is enough to make many patients a little anxious or alarmed on their first trial of electrical treatment (§ 185).

With battery currents, the galvanometer provides the means of regulating the dosage. For most forms of local treatment, a current ranging between five and ten milliampères is an average quantity, and may be too much for children, or sensitive or nervous people, at the commencement of treatment; and the current must not be switched on or off abruptly, but gradually, the patient being carefully watched for any signs of pain or discomfort. Deep-seated parts should have larger currents administered through large electrodes. The apparatus must be well made, and should be tested from time to time to see that it is in perfect order; when applications are made to any part of the head or neck, additional care must be exercised, the effect upon the brain being very peculiar and unpleasant, especially at make and break. Toleration of large currents is rendered possible by the use of large electrodes to reduce the density of the current per unit of area.

The usual duration of each application is ten or fifteen minutes.

The number of applications varies very much, usually a considerable number are required. In most electrical treatment one cannot expect a rapid cure, but rather a gradual slow improvement. In some cases of infantile paralysis it may be necessary to continue treatment for several years. As a general rule it may be said that a month of treatment, with two or three applications a week, will be enough to produce permanent benefit, but it is not possible to lay down any precise rules. It is usual for improvement to begin early if the treatment is likely to do good. In that case the patient will be encouraged to persevere. If at the end of a month of regular treatment there is no visible change, or if the improvement

has ceased to be progressive, then the treatment may be discontinued.

199. **The choice of pole.**—With the secondary currents of an induction coil the influence of pole is reduced to a minimum, and the two electrodes may be considered to be of equal, or nearly equal, value; with the "primary" current there is a positive and a negative pole, a point to be borne in mind in electrical testing; with continuous currents the differences in the effects produced at the two poles are well marked.

The sedative effect of the anode would seem to determine its use in painful states, while the stimulating effect of the kathode, and the greater ease with which it causes muscular contraction, have determined the use of the negative pole in the treatment of paralysis, as well as in the testing of the reactions of nerve and muscle. It is not possible to generalise further about the choice of pole, but instructions will be found in the chapters on treatment.

The rule laid down by Remak for the direction of the flow of current was, that the current should pass along the nerve fibres in the direction in which they conduct, namely, downwards to the periphery for treatment of motor affections, and upwards from the periphery for sensory affections.

200. **Ascending and descending currents.**—When the electrodes are so placed, that a line drawn from the positive to the negative poles runs in a direction from centre to periphery, the current may be spoken of as a "descending current," and conversely it may be called an "ascending current," when the anode is more remote and the kathode more central.

It is now more usual to define an electrical application, not by speaking of the ascending or descending direction of the current, but by reference to the sign of the pole which is used as the active electrode, and inasmuch as the indifferent electrode is commonly applied to the trunk while the active electrode is applied to a limb, the current would usually be a descending current when the active electrode was negative, and ascending when the active electrode was positive.

The expressions "ascending" and "descending" current convey the idea that the direction of the flow in the interpolar region is of importance, while the phrases "the use of the negative pole," "the application of the anode," and so on, need not necessarily be taken to do more than signify the polarity of the electrode applied to the affected part.

Reference to fig. 108 shows that the current in traversing any particular point must leave it with a polarity opposite to that with which it enters it, for example, the nerve trunk represented in the figure as traversed by the current, is negative to the parts which lie nearer to the electrode, and is positive to those which are further away. All that can fairly be said of the region surrounding the positive electrode is, that it is positive to areas which are more remote.

We may consider the direction of the current as less important than the influence of the poles; and we should, therefore, speak of the choice of pole, rather than the choice of the direction of the current, because the current does not run in straight lines from anode to kathode; however, the distinction between direction of flow and choice of pole is after all a subtle one. To apply the kathode to the paralysed thumb muscles, the anode being at the nape of the neck, may reasonably be spoken of either as treatment by a descending current, or as treatment by the negative pole. With the indifferent electrode central, and the active one peripheral, it is permissible to speak of treatment with descending currents, when the active electrode is the kathode, and of ascending currents, when it is the anode; the words ascending and descending having reference to the general direction from anode to kathode, and not implying any theory of the physiological or therapeutical importance of the direction of the flow at the seat of disease.

201. **Methods.**—Most electrical treatment is now carried out by using a single active electrode, and an indifferent electrode. The active electrode may be two, three, four, or five, or more inches in diameter, according to the extent of surface to be included in the treatment, and the magnitude of the current used; the electrodes must be well moistened with warm water, the indifferent one in its sheath is then pushed down the back of the neck for patients who are dressed and sitting up, or it is placed under the hips for patients lying down. The part to be treated is then bathed with warm water, and the active electrode applied, and the current slowly raised to a proper strength, with the battery current three, five, or ten milliampères or more if necessary. The active electrode is then moved slowly over the whole of the affected part (labile method), or it is kept still in one place (stabile method). If direct current is being used the circuit may be closed and opened by the use of a key in the

electrode handle (§ 76) for the sake of producing muscular contractions, or may be even reversed by means of a commutator, for the same purpose. These reversals are especially powerful in exciting muscular contraction.

It is sometimes useful to have the indifferent electrode in the neighbourhood of the part under treatment; by doing this the current can be concentrated through the part tested. In testing or treating the muscles of the hand, for instance, it is often convenient to lay the indifferent electrode under the palm while the active electrode is applied to its dorsal surface and *vice versâ*.

Sometimes a bowl of water is useful as a medium between the electrode and the patient, who may dip a hand into the water in which one electrode is placed, and have the other electrode at the nape of the neck, or he may have two such bowls of water and put one extremity in each, when the current is to traverse two limbs at once. See § 154, on the use of the arm-bath for purposes of treatment.

When painful sensory impressions are desired, a metallic brush electrode of very fine wires may be used; a long secondary coil of many turns is most suitable for use in this case (§ 64).

The interrupted current is to be employed where stimulating effects are chiefly desired, and with this object it is valuable in the treatment of paralysis and anæsthesia. Where involuntary muscle is to be thrown into action the direct current with interruptions and reversals is more effectual.

In most local applications of electricity the manipulations consist in moving the wet surface of the active electrode slowly over the moistened skin covering the part under treatment with a sliding movement. For this to take place comfortably a proper degree of moisture is necessary. If the skin or the surface of the electrode be too dry the latter will not slip smoothly, but will seem to stick, or move harshly. When this is felt the electrode must be moistened afresh. A little soap on the surface of the active electrode makes it work very smoothly.

It must not be assumed that the degree of benefit from treatment can be measured by the amount of visible contraction of the muscles, for in addition to the exercise so produced there are vaso-motor effects, and reflex effects through the centres in the cord, both of which take part in bringing about the final results.

The duration of each application should be about ten minutes, and this time must be distributed over the muscles or other parts needing treatment. When the dry brush and painful currents are employed, five minutes will usually be quite long enough, and the patient must on no account be reduced to a state of exhaustion from over-treatment. The operator should always try the current by experiment on his own muscles, in order to know exactly what amount of discomfort or pain his patient is called upon to bear.

202. "**General electrisation.**"—The old plan of treating patients with the currents of a coil or a magneto-machine by means of metallic electrodes placed in the two hands, may be regarded as a rude attempt at general electrisation. Drs. Beard and Rockwell have described a process of "general faradisation" which is intended as an improved kind of general electrisation.

In all procedures of general electrisation the object aimed at is to bring every portion of the body under the influence of the treatment so far as is possible.

Beard and Rockwell propose to accomplish this by placing one pole of the induction coil under the feet or gluteal region while the other is moved over the general body surface. The patient should stand or sit upon the surface of a large metal electrode, covered with moist flannel and kept warm by means of a hot water bottle or some other contrivance, as the treatment lasts for from ten to twenty minutes. The active electrode is then to be moved over the various parts of the body, two or three minutes being given to the head, neck, back, abdomen, arms, and legs, in order.

Where an electric bath exists general faradisation of this kind will not be needed.

In all general electrisation the strength of current should be so regulated that the sensations felt by the patient should be of an agreeable nature, a pleasant thrill without any pain or discomfort.

The results of general electrisation are mainly tonic in their nature, a feeling of vigour follows, depression or fatigue are relieved, the appetite is increased, the patient sleeps more soundly, there is an increase in the firmness of the muscles, and an improvement in the circulation. In some patients these results follow promptly, in others their development is more gradual.

In general it is sufficient to apply the treatment two or three times a week, or every other day. Currents sufficiently strong to cause some muscular contraction should be employed as soon as the patient has become accustomed to the treatment and is able to bear them without apprehension.

The electric bath produces the same results with more comfort to the patient, and has superseded the above described process.

The methods described in the Chapter on "high frequency" may also be used for general electrisation. The static machine (§ 126) may also be employed for this purpose, but the electric bath with sinusoidal current or induction coil current is the best way of obtaining a good result.

203. **Galvano-faradisation.**—Dr. de Watteville has recommended the simultaneous use of the continuous and the interrupted currents under the above name. The method consists in "uniting the secondary induction coil and the galvanic battery in one circuit by connecting with a wire the negative pole of the one with the positive of the other, attaching the electrodes to the two extreme poles and sending both currents together through the body." We are told that "the effects of the faradic current are greatly enhanced by a simultaneous galvanisation, because the points upon which the stimulus falls are in a state of exalted excitability or kathelectrotonus. Owing to the 'refreshing properties' of the galvanic current upon muscle, the fatigue and exhaustion which might otherwise be the consequence of energetic faradisation are avoided." Dr. de Watteville had a very high opinion of the advantage of this mode of treatment, particularly for electrisation of the abdominal viscera, and in rheumatic conditions, and in atrophic paralysis. The method is still occasionally used.

The strength of each component may be about the same as when either is being used alone.

204. **Central galvanisation.**—This is a plan of applying continuous currents to the nerve centres, also introduced by Drs. Beard and Rockwell as a means of general electrisation. It consists "in placing the negative pole at the epigastrium, while the positive pole is applied to certain parts of the head (chiefly the vertex and forehead), to the sympathetic and pneumogastric in the neck, and down the whole length of the spine from the first to the last vertebra." It is said to be useful in cases of hysteria, neurasthenia, sleeplessness, dyspepsia, and

other complaints. The duration of each application may be for ten minutes, and the position of the negative pole should be changed a little from time to time, to prevent any electrolytic effects upon the surface of the skin beneath it. The strength of current should range between five and ten milliampères, according to the part under treatment, and may be reduced to two or three milliampères for the applications to the head if the patient appear to be very susceptible.

Among recent writers upon central galvanisation, Dr. Armstrong* of Buxton may be mentioned. In his paper he advises currents of one to five milliampères for the head and up to twenty milliampères for the spine, with sittings of ten to thirty minutes repeated three or four times a week, or daily. He quotes cases in which he obtained good results in palpitation and irregular action of the heart, in exophthalmic goitre and in conditions of cerebral exhaustion and in neurasthenia, and enumerates among the good effects obtained that the patients treated had improved appetite and digestion, spoke of feeling brighter, their bowels were more regular in action, and they slept better. He mentions that with currents of too great strength, or too abruptly made and broken, unpleasant effects may follow, especially in the applications to the brain. He does not insist upon the epigastric position of the indifferent electrode so strongly as is done by Beard and Rockwell.

Electrical applications to the nerve centres will probably be found useful in many cases of the kinds just mentioned. Patients who have been under treatment for affections of the auditory apparatus, by means of electricity applied to the sides of the head, have frequently reported that the applications exercised a good effect upon their general health, and Capriati's experiments (§ 177) with healthy individuals have shown that the application of currents of ten to fifteen milliampères to the spine for ten minutes produces a marked effect upon the muscular power.† This favourable effect is commonly observed with patients under treatment.

It is probable that a more extended course of observations upon the influence of spinal and cerebral electrification in disease would give encouraging results, particularly in func-

* *Transactions of the Royal Medical Society of London*, vol. xxi.

† "Influence de l'électricité sur la force musculaire." *Arch. d'électricité médicale*, November, 1899.

tional conditions, and possibly in many neurasthenic states. The battery current must be employed, as that of the induction coil does not penetrate so well to the deeper parts of the body.

205. **Galvanisation of the cervical sympathetic.**—In former times this procedure was much recommended, but it is not clearly proved that the cervical sympathetic has ever been appreciably influenced by electrical treatment. The ordinary physiological effects on the pupil, or on the blood vessels of the head and neck, of stimulation of the sympathetic are not produced.

In Erb's opinion it should be carried out "in every case where it is hoped to act on the circulation and nutrition of certain parts of the brain." The usual mode of applying the treatment is to place a medium sized electrode (kathode) at the angle of the jaw, with its surface directed backwards and upwards towards the vertebral column. The indifferent electrode should be applied to the opposite side of the back of the neck, on a level with the fifth, sixth, or seventh cervical vertebra. The current should range between two and five milliampères, with a duration of one to three minutes, the application stabile. In certain cases both sides may be treated successively. As this treatment must involve all the other important nervous parts of the neck and the base of the skull, as well as the cervical sympathetic, it would be better to adopt Dr. de Watteville's suggestion, and speak of *subaural galvanisation*, rather than of galvanisation of the sympathetic.

206. **General electrisation.**—By virtue of the stimulating effect which is produced by a general application of electricity to the whole body, one is enabled to obtain good results in the treatment of many morbid conditions.

The advantages of general electrisation in disorders of nutrition have been repeatedly insisted on, particularly by D'Arsonval and those who have followed his teachings. The group of general diseases which are characterised by defective or perverted nutrition, includes not only simple anæmia, chlorosis, debility, and neurasthenia, but also rickets, gout, rheumatism, rheumatoid arthritis, diabetes, obesity, &c.

In the treatment of these disorders the mode of general electrisation most generally employed is that of treatment by the electric bath with sinusoidal current. The other modes of applying electricity to the general system have similar effects,

but are most probably of less general utility. They include the general applications of high frequency currents, and of statical treatment, and the methods of "general faradisation" and "central galvanisation" already described in the present chapter.

The influence exercised by general electrisation in states of defective nutrition, and in convalescence, may be presumed to involve two separate factors, the first being a stimulation of the activity of nutritive exchanges, leading to a growth or renewal of the tissues, while another, which may be equally important, is the stimulation given to processes of elimination of waste products or toxic substances from the system. General electrisation appears to operate in both of these ways.

In gout, in obesity, and in muscular rheumatism, electrisation has been applied mainly with the idea of promoting elimination, or of correcting improper assimilation, and a good deal of evidence can be brought forward to show the utility of electrical applications in these morbid states.

207. **Anæmia and chlorosis.**—General electrisation is not often resorted to for the treatment of these conditions, because good results can generally be obtained by simpler means. In obstinate cases where ordinary treatment does not answer satisfactorily, the electric bath should be tried. By its use the metabolic processes of the patient can be so efficiently stimulated that increased appetite and vigour can be secured for the patient, with improved colour, and a marked gain in weight. Under these conditions the catamenia will probably be re-established in a proper manner. I have several times seen excellent results follow treatment by electric baths when anæmic patients were not doing well under iron, and consider that the results of general electrisation are distinctly valuable in such cases. In chlorosis, and in some other forms of anæmia, we have to do with simple forms of defective nutrition in which a simple electrical stimulation suffices to bring about a change for the better.

208. **Delayed convalescence.**—When the recovery of patients after serious illnesses is delayed, they should be treated by general electrisation. After the specific fevers, and in many other conditions, electrical stimulation is of great value. After influenza a course of treatment, as by electric baths for instance, promotes the return of the patient's health to a normal standard.

The mental depression disappears and the bodily strength returns, and the period of convalescence, which is so often prolonged in patients who have had an attack of influenza, is notably reduced; even serious mental failure after influenza has rapidly vanished under general electrical treatment by the electric bath (see § 218). Tripier has stated that he had never seen such rapid and remarkable good effects follow any other treatment in cases of anæmia, and especially in convalescence after acute illnesses as those which followed general electrisation in the electric bath.

209. **Rickets.**—This is another condition of simple defect of nutrition which is benefited by general electrisation. It is surprising to see how quickly children with rickets begin to improve in general health, in their powers of standing and walking, and in weight, under the stimulating effect of electrical treatment. In Italy, Sagretti and Tederchi have reported a number of cases of rickets cured quickly and completely by electric treatment administered by the bath method.

Severe cases of rickets referred for treatment to the electrical department at St. Bartholomew's Hospital, have fully borne out the accounts given by those writers.

210. **Nervous debility and neurasthenia.**—In neurasthenic states the methods of general electrisation are of great value, especially the electric bath, which answers very well to the indications for treatment required by these cases. Direct applications to the nerve centres with the constant current (see § 204) are also useful. The condition described under the general term neurasthenia, is a condition of general debility or of debility affecting chiefly the nervous system. Often it can be traced to some definite disturbing cause, such as mental worry or a severe illness; the digestion becomes impaired, and this keeps up a state of defective nutrition, from which it is difficult for the patient to escape.

In other cases errors or neglect in matters of diet, extending over a long time, may be the cause of the neurasthenia, and the patient himself may be quite unconscious of this. Dyspepsia is very commonly present, and should be attended to. Many people tend to become neurasthenic in the slighter degrees when their daily cares exceed a certain point, and when business matters or other troubles begin to spoil the appetite, and to interfere with proper exercise, with the regularity of meals, or

with sleep, then troubles of the neurasthenic sort are likely to begin.

The treatment of neurasthenia requires the use of some method of general stimulation, and it is in this capacity that general electrisation is so useful.

I have had opportunities of seeing the effect of general electrisation upon a number of these cases, and I am satisfied that vigorous stimulation, carried out two or three times a week, in the electric bath with the induction coil or sinusoidal current, has far more effect upon neurasthenics than any other mode of treatment. It should be used in conjunction with proper rules for diet and regimen, and the original depressing cause of the disease should be found, and if possible, eliminated. If this cannot be done no treatment will be of much use. For instance, where domestic unhappiness or discontent is a factor, one may treat in vain.

211. **Muscular rheumatism.**—Bordier,* in discussing the significance of muscular rheumatism, points out that the innervation and the nutrition of a muscle affected by rheumatism is clearly abnormal, the characteristic feature being the pain which is felt when the muscle is thrown into voluntary contraction. This condition of painful stiffness is so much like that which is felt in a muscle after a period of severe over-exercise that the inference may be drawn that in both cases the cause might be of a similar nature, namely, the presence of waste products in the tissue of the muscle. The good effects of electrical applications in so-called muscular rheumatism might be ascribed to the great effect which rhythmic tetanisation or contraction has in promoting the flow of blood through the vessels of the contracting muscle, as by so doing the prospects of the removal of some of the waste products by the blood stream would be notably increased.

Clinical experience shows that muscular rheumatism is much benefited by general electrisation. Some writers have thought that the combination of direct with induction coil currents (galvano-faradisation) is specially indicated in such cases, and it is possible that the electrolytic action of the direct current upon the migration of the ions may tend to supplement the effect of simple stimulation produced by the induction coil currents.

212. **Gout.**—General electrisation has been used in gouty

* *Précis d'électrothérapie*, Paris, 1902.

conditions with the view of modifying nutrition, and of stimulating the elimination of uric acid. Of late years high frequency currents have been extensively tried. Although some success has seemed to follow their employment it is to be noted that several cases have been recorded in which an attack of acute gout has seemed to have been determined by the high frequency applications. In many of the more indefinite gouty manifestations general treatment by means of the electric bath and sinusoidal current has been successful. Direct currents of large magnitude have also been recommended.

The application of electrolysis and the migration of ions to the treatment of gout by means of the dipolar bath with salts of lithium is worthy of note.

Guilloz* has reported two cases of severe and old-established gout which were successfully treated by local monopolar electric baths containing lithium carbonate. He recommends large currents up to 200 milliampères, and places the positive pole in the bath with the affected limb or limbs, the negative pole, of large size, is applied to the back. The time of the applications is from twenty to thirty minutes. His patients were also treated by auto-conduction and high frequency currents. The first patient was twice treated for two severe attacks, each time with rapid good effect. The second patient also did well in spite of the fact that Dr. Guilloz says that he continued to follow a dietary which was "of the most detestable" and that his excesses in eating and drinking were renowned ("*passent a l'état légendaire*").

Bordier† has published a case in which a treatment of the same kind was carried out. The patient had numerous large uratic concretions of both hands and of the elbows. Arm-baths containing two per cent. of lithium chloride were used, the circuit being completed through two large pads (kathodes) applied to the body of the patient; 80 to 100 milliampères were well borne, and the treatment was continued for half an hour daily.

After use for some days the liquid in the arm-bath began to deposit a sediment, and at the close of the treatment this was collected and analysed. It was found to consist mainly of calcium carbonate but contained undoubted traces of uric acid.

* *Arch. d'électricité médicale*, June, 1899.

† *Arch. d'élect. médicale*, 1900, p. 531.

At the end of a month the patient was much improved, the swelling of his hands had diminished by measurable amounts, and the tophi on the knuckles had become softened; one which was punctured discharged calcium urate in a semi-fluid state, whereas before treatment was begun they were quite hard and solid.

213. **Diabetes.**—Much has been written on the treatment of this disease by high frequency methods, and cures have been reported. In most of the recorded cases a notable reduction in the daily excretion of sugar has been produced and the patient's condition has at the same time been improved. In spite of this evidence it remains very far from certain that even a majority of diabetics respond to high frequency by a decrease in the amount of sugar discharged daily.

Other forms of general electrisation seem capable of modifying the daily discharge of sugar. I have notes of several cases in which there was a striking diminution of sugar excreted on the days on which electric baths were given, but in spite of this no real progress towards recovery was made.

214. **Obesity.** — The treatment of obesity by electrical methods is carried out as follows. Large electrodes, well moistened, are applied to the thighs, to the abdomen and to the lumbar region. Continuous currents are made use of, and if the electrodes are properly arranged a magnitude of 100 or 150 milliampères can be borne.

Applications lasting half an hour or more are given. Care must be taken to avoid injury to the skin by a proper disposition of the electrodes, and by good conducting contacts between them and the skin surface. In addition there may be a brisk stimulation of the muscles of the abdomen, thighs, and legs by a procedure of galvano-faradisation (§ 203). The pulse must be watched, and the treatment adjusted accordingly (Bordier).

215. **Rheumatoid arthritis.**—This disease may be considered here because it is one for which general electrisation is undoubtedly useful. Applied in the form of the electric bath with sinusoidal current, general electrisation is of great value in cases of rheumatoid arthritis. High frequency treatment has also been extensively employed in recent years for the treatment of this complaint, and in some cases the results have been satisfactory. The electric bath method, however, is probably better. In many of my own cases marked good has followed

this treatment, and the results in some of them have been most striking.

It cannot be said at present that a real cure of this disease can be achieved by electrical methods, and the results hitherto obtained are rather palliative than curative. Nevertheless, in comparison with the alternative modes of treatment the method of general electrisation by means of the electric bath is perhaps the best at our command.

216. **Applications of electrical treatment.**—It is a matter of importance that all electrical treatment should be carried out by the medical man himself whenever this is possible, and if it is not possible for him to do so then at least he should supervise the treatment as often as he can. Except in the very simplest applications of electricity, the results of entrusting the treatment to unqualified persons are unsatisfactory, and the usual consequence is to bring electrical treatment into discredit, rather than to benefit the patient. When the expense of electrical treatment applied daily for long periods by a medical man may prevent the patient from giving the treatment a fair and prolonged trial, it may sometimes be desirable to teach the patient or a relative or a nurse what to do. This is particularly the case in chronic conditions, where the necessary manipulations are quite simple and where a successful result from the electrical treatment cannot be predicted with certainty. The aid of electro-therapeutic methods is often invoked only when every other treatment has been tried without success, and thus it happens that many cases have already become chronic and difficult to influence before they come for electrical treatment. Moreover the mode of action of electricity upon the tissues of the body is in its essence a gradual one, working as it does by a slow rebuilding or regeneration of the damaged organ or function, and requiring time and the exercise of patience and perseverance in its applications. It is among the poor and in hospital patients that one has the best opportunities of seeing the good which can be done by electrical treatment in chronic cases. In that class of patient considerations of expense do not interfere to cut short the treatment prematurely, nor are hospital patients so ready to throw up one kind of treatment in order to try something different. Thus it is a not uncommon experience to have similar cases under treatment at the same time, the one at the hospital and the other as a private patient, and to see the

latter throw up the treatment when half through with it, while the former goes steadily on and makes a good recovery.

Whenever the treatment must be carried out by a nurse she must be given a few careful lessons in the anatomy of the part to be treated, and in the manipulations to be performed at the commencement of the case. She must be supervised at frequent intervals by the medical man in charge of the patient, who should never omit to make measurements and tests from time to time, to ascertain what progress is being made, and to prevent the case from being left in the sole charge of the nurse.

In the particular case of the treatment of infantile paralysis, applied daily for a long period of time, it is impossible for the medical practitioner to be present on every occasion of treatment, and a responsible person, the nurse or mother, must be carefully shown what to do for the particular case, but the periodical testing and supervision by the medical man himself must not be omitted.

CHAPTER XII.

Electrical Treatment in Brain Diseases. The Neuroses.

Cerebral disease. Mental diseases. Epilepsy. Chorea. Hysteria. Insomnia. Tremors and spasm. Writers' cramp. Tetany. Exophthalmic goitre. Migraine and headache. Hemiplegia.

217. **Cerebral diseases.**—The treatment of diseases of the brain by the direct application of electrical currents to the skull has not received much attention during recent times. This has been due to various causes. Some have thought it useless, others have thought it dangerous. Erb's* writings on the subject contain abundant proof that treatment applied to the brain is neither useless nor dangerous, and the treatment of diseases of the brain by the direct application of electrical currents is a section of electro-therapeutics which opens up an extensive field for research.

Induction currents are not very suitable for cerebral treatment. It is not easy to show that they produce any intra-cranial action at all, and it has been said that they do not penetrate the skull. Certainly it is not possible to produce localised stimulation of the separate motor centres of the cortex by induction coil applications to the skin over the Rolandic area.

The resistance of the bones of the skull has been put forward to explain this want of effect of coil currents on the motor cortex. Bone, however, conducts moderately well, though not so well as the soft tissues of the body, and it is quite easy to produce cerebral effects with direct currents, and no one has yet suggested that the ohmic resistance of bone is greater for interrupted currents than for direct currents. Some other explanation is therefore necessary. Owing to the spherical shape of the skull, diffusion of current (§ 160) is favoured, and therefore the density of current is greatly lowered at a short distance away from the electrodes. For the same reason the stimulation becomes evenly divided over the whole of the area between the

* "Electrotherapeutics," translated by De Watteville. Von Ziemssen's "Handbook of General Therapeutics," vol. vi., Smith, Elder & Co., 1887.

electrodes, and the effects produced are likely to be effects of stimulating the brain as a whole rather than those of stimulating any small part of it.

Moreover the scalp is very sensitive to induction coil currents, and a painful effect is produced upon the skin in contact with the electrode when the actual current is still very small; so small that when scattered by diffusion in traversing the deeper tissues it produces so slight an effect that this is masked by the painful sensations at the point of contact between the electrode and the scalp.

Battery currents produce effects upon the brain which can readily be perceived (§ 174), and as they are generally unpleasant it is advisable to use care when applying them for treatment. The precautions necessary are to avoid sudden makes and breaks of circuit and to apply the electrodes in a symmetrical or median position, in order that the effects upon the two hemispheres shall be as far as possible balanced. If currents are carelessly applied the patient will be disturbed by giddiness, by a tendency to faint, and by flashes of light produced through stimulation of the optic nerve. Nausea may be felt and nystagmus observed, and in consequence the patient may lose confidence in the treatment, or may be afraid to continue with it.

The objects to be hoped for from applications to the skull in cerebral disease are to assist the circulation through the brain, to remove congestion, and to improve nutrition. There is every reason to believe that the state of nutrition of the brain might be as favourably influenced by electrical applications as that of the nerves and muscles.

Prof. Leduc of Nantes (*Arch. d'électricité médicale*, May, 1899) in a lecture on Cerebral galvanisation relates the case of an elderly Judge who had been under his care at one time for facial paralysis. He was treated by direct current and soon recovered from his paralysis, but afterwards continued to come at intervals for more treatment because of the comfortable feeling of increased mental vigour which the galvanisation of his head and neck afforded him. His words deserve quotation. He said, "I feel lighter, and my ideas are more clear. I can concentrate my attention more closely upon my work, I struggle more successfully against the sleep-producing effect of long pleadings; I grasp more clearly the arguments which are advanced before

me, and I can weigh them more exactly; in fact, I find my intelligence is brighter and my work is more easy to do, and for that reason I come to you for an electrical application whenever I am confronted by a fatiguing or difficult piece of work."

Prof. Leduc concludes his lecture with the following statements:—

1. The brain is quite accessible by the battery current.

2. Applications to the brain are free from danger, and if carefully applied are free from discomfort.

3. Negative applications appear to excite the functions of the brain, while positive seem to have a calming and depressing action.

4. There is reason to hope for good effects in many diseases of the brain.

5. Negative applications afford a means, probably the best means, of relieving the effects of mental overwork, and of raising the intellectual powers to their highest level.

A patient of my own, who had been receiving electrical treatment for nerve deafness, though not very greatly improved so far as her hearing was concerned, was so conscious of the good effect produced upon her general condition as to be most anxious that her husband should also be treated in the same way.

218. **Mental diseases.**—The abundant evidence which we possess of the value of general electrisation in the simpler forms of nutritional failure seems to point to the importance of applying the same kind of treatment in certain forms of insanity or mental failure, especially if the general state of nutrition is not maintained. As a rule cases of this kind are not often met with in general practice, nor among the out-patients of general hospitals, and it will rather be in asylum practice that opportunities for trying electrical treatment will arise. A considerable amount of evidence has already accumulated to show that something may be done in this way. A valuable summary of the position up to about 1885 will be found in Erb's work on Electro-Therapeutics, together with numerous references to the writings which should be consulted in connection with the subject. Three cases which have come under my own experience may be mentioned here. One was that of a man referred to me by Dr. Gee with a note saying that the patient showed many of the signs of progressive dementia, but that as his symptoms dated from a recent attack of influenza he might

receive benefit from electricity. The patient recovered rapidly from a short course of sinusoidal bath treatment, he recovered his memory which he had completely lost, and was able to go back to his work. Another patient was a shorthand writer who had broken down in health completely. He was strange in his manner and sat huddled up in a dejected attitude. His wife said he was much changed in temper, and told me that on one occasion he had been found wandering about and had been brought home by a policeman. When he came he was put on sinusoidal baths twice a week. A gradual improvement began and all his symptoms slowly left him. After three months he was able to begin work again, and has continued well for more than four years.

A third case is very much like the last. A man of forty began to grow more and more helpless. He became unable to find his way in the street; he stumbled easily, and several times fell down without adequate cause. His speech became slow and he could attend to no business, and it was uncertain whether he understood what he read in the newspaper. Under electric bath treatment there was a slow improvement, perceptible first to his wife. In about two months' time he was able to come to the hospital alone instead of being brought there by a friend. Treatment was continued for nearly a twelvemonth, and during the last part of the time he was able to attend to the book-keeping of his wife's business. He spoke quickly and to the point, and no longer stumbled or fell down, and he described himself as "practically well." There was a gain in weight both in his case and in the preceding one.

The following communication from Dr. Robert Jones is noteworthy as showing a simultaneous mental improvement and augmentation of body weight in a series of cases treated under his supervision at Claybury Asylum by general electrical stimulation by the bath method, using induction coil currents.

"I have tried the electric baths in the case of adolescents mostly. In these and others the form of insanity was that of melancholia, some of the cases presenting well marked melancholia attonita (or anergic stupor).

"These cases are marked by a gradual deterioration as a rule; they stand or sit about in a fixed or passive attitude and have almost always to be considerably coaxed (if not forcibly fed) in order to get them to take nourishment. The mental

condition is so unsatisfactory that some persons call the disease primary dementia and it is certainly not a very curable form.

"After my conversation with you and my encouragement by your method of bath treatment, I tried it upon eighteen males and five females. The record of weight in the case of the females was not kept; of the five cases all improved greatly in health; two were phthisical, but whilst undergoing bath treatment both gained several stones in weight. One died of phthisis; of the others one was discharged recovered, one has developed epilepsy, and one has recovered sufficiently to lead a useful life as a helper in the asylum.

"Of the eighteen men, nine have left the asylum (six recovered, two relieved, and one improved but not recovered). All the men gained weight under treatment (they were weighed weekly and the record has been kept), the average gain of the nine who left the asylum being seven pounds during the bath treatment, which lasts for an average period of about seven weeks, but many received baths during nine or eleven weeks. The greatest gain of one case whilst under treatment was twenty-two pounds, the next nineteen pounds. Of the nine cases remaining under treatment, one is phthisical, one is suffering from progressive muscular atrophy; the others are considerably improved mentally, the stupor or profound melancholia having quite passed off, but they have not been well enough to be discharged from the asylum. I consider the results to be satisfactory. So little has yet been done in regard to the systematic treatment of the different forms of insanity by electricity that it is perhaps premature to form definite conclusions, but I consider that in electric baths we have an excellent and valuable stimulant to metabolism.

"I should especially recommend electric baths in melancholia in adolescents and apathetic cases such as I have referred to. Certain puerperal cases of melancholia have also done well under treatment."

219. **Epilepsy.**—This has been attacked by electrical methods, but without any practical advantage. Arthuis stated that he had seen good results follow from electrostatic treatment.

Althaus gives three cases where treatment at once diminished the frequency of the attacks, and went so far towards effecting a cure that the intervals between the fits was prolonged from

a few days to two months. Erb also reports that he has received a decidedly favourable impression from the treatment of epilepsy by the constant current. He advises that the anode be placed first on the side of the forehead, with the kathode to the nape of the neck, with a weak current for one minute, and secondly in the middle line of the head in front with the same current and for the same length of time, the kathode being over the occiput. The treatment of the seat of the aura as well is recommended by Althaus.

220. **Insomnia.**—General electrisation frequently produces a tendency to sleep afterwards. The electric bath has an especially strong effect in predisposing to sleep. So has the static charge (positive) with head breeze. Armstrong has found central galvanisation very useful (§ 204). Bonnefoy has pointed out that statical applications are specially indicated in subjects with a low arterial pressure and are unlikely to be of service in the opposite condition of raised arterial tension.

High frequency applications, which have a tendency to reduce blood-pressure, should be chosen in preference for patients of this latter class.

221. **Migraine and headache.**—In typical migraine the results of electrical treatment are disappointing. In mild forms the headache may be relieved by applications of the constant current longitudinally to the head. The static brush discharge to the scalp is also of service in some cases.

Central galvanisation (§ 204), electrostatic charging, the electric bath, and high frequency treatment applied systematically between the attacks will often succeed in reducing the tendency to migraine. Many writers have preferred some form of general electrisation for migraine, on the ground that it is a manifestation of impaired nutrition requiring general rather than local treatment.

The simple headaches of debility or fatigue are often dispelled at once by static charging. Constipation headaches are unaffected or made worse by this treatment.

222. **Hysteria.**—Hysterical affections have been very largely treated by electricity, and from the peculiar nature of the affection, good results have followed the most diverse forms of electrical treatment. The moral effect of the treatment, particularly when it is associated with sparks or with shocks, is suitable to the state of mind of hysteria, and therefore the

literature of Medical Electricity, from the time of John Wesley's "Desideratum" onwards, is full of more or less wonderful cures of such cases by electricity, acting no doubt in a psychical way. At the same time the action of electrical treatment lies rather in the direction of dispelling symptoms than of curing the morbid state, and it is necessary to be prepared for occasional difficulties and disappointments, even in hysterical cases, although good results will often be obtained. We must also be careful not to claim too much for the electrical part of the treatment when it is successful, for it may happen that the touch of an electrode will cure even when there is no current. Several cases of this kind have come to my notice. Strong shocks have often been used for cutting short an hysterical fit, but the most useful rôle of electricity in hysteria is for the removal of paralysis, anæsthesia, or spasm; for these symptoms the induction coil is most usually employed, either with an ordinary electrode or with the dry metallic brush. Statical treatment, especially the treatment by sparks, is also valuable in these cases, and has been very largely practised.

Hysterical aphonia can sometimes be dispelled by coil currents applied to the throat from outside, and for the most part this method is as good as the direct application of the electrode to the fauces, or to the larynx.

The electrical treatment of hysterical symptoms does not depend merely on the severity of the applications; the treatment may be briskly applied, but pain must not be deliberately inflicted. In the treatment of functional aphonia by sparks or shocks, there are cases where the patient becomes alarmed and screams out aloud and so becomes cured. Others suffer in silence and do not cry out, and these are not so easily cured.

For the hysterical condition, as distinguished from the special symptoms, it is advisable to use general electrisation, and especially the electric bath or treatment by statical charging and breeze.

Hysterical patients are considered to be bad subjects for high frequency treatment.

An important consideration is the diagnosis between hysteria and organic disease of some obscure kind. It is not at all uncommon for hysteria to be associated with serious disease, for instance with phthisis; moreover, when the diagnosis of hysteria

has been based upon the complaint of a persistent localised pain in a female patient, it may after all turn out that the pain is due to some serious latent mischief. I have known two cases where female patients with early malignant disease of the vertebræ complained of persistent pain and were supposed to be suffering from hysteria alone.*

223. **Chorea.**—Statical electricity has been successfully used in this disease. In 1849 Dr. Golding Bird† strongly advocated its use in this disease and reported thirty-seven cases. Of these thirty had been cured by the treatment, while five of the others were relieved. The treatment adopted was the application of sparks to the spine. The patients were insulated and connected with one of the conductors of the electrical machine. A ball-electrode with insulated handle was attached to the other conductor, and sparks were applied to the spinal column and the affected limb, until a papular eruption was produced. In the case of children the mother or nurse was insulated with the child in her arms, and sparks were applied to the child's back and limbs as before.

The shocks from a Leyden jar were found to be decidedly harmful.

In *Guy's Hospital Reports* in 1853, Sir William Gull reported twenty-five cases of chorea treated by statical electricity. Nineteen were cured and five improved; only one resisted the treatment. He says: "The fact stands well established that electricity is at present to be ranked amongst the means at our disposal for the cure of chorea, and that in severe cases its effects are often truly surprising. Where other means cannot be employed; when the patient is scarcely able to swallow; where the skin is abraded from the prominent bones of the emaciated frame; when the powers of life seem nearly exhausted, sparks of electricity drawn from the whole length of the spine will often, after a few repetitions, effect a favourable change, and enable us to administer other means of cure." In spite of this emphatic testimony the treatment is now-a-days neglected.

In the few cases which have come under my own notice I have found such statical treatment very useful.

* Cf. Dr. Buzzard, *Brain*, 1890. "On the Simulation of Hysteria by Organic Disease of the Nervous System."

† "Lectures on Electricity and Galvanism," London, 1849.

With modern machines the negative breeze to the spine would probably alarm the patient less and prove as efficacious.

It often happens that patients seem to recover imperfectly from chorea, because certain habitual movements remain when the disease has otherwise disappeared. For these late symptoms electrical applications are very suitable. I have seen them quickly dispelled in several such cases by a course of electrostatic treatment with sparks. Indeed all those which I have been asked to treat for this condition have recovered within two or three weeks.

The paretic states which are often left after chorea may be treated by electricity with great advantage.

General electrisation in the electric bath is also useful. It is probable that the high frequency effluve to the spine would act equally well.

224. **Spasm and tremor.**—The numerous forms of tonic and clonic spasm and of tremor come often under electrical treatment by reason of their incurable character. When the symptoms are due to a degenerative process in the nerve centres, as for instance in paralysis agitans, in disseminated sclerosis, and in hemiplegia, electricity is not likely to be of service. Other forms of spasm and tremor, which may be of central origin, are capable of cure or amelioration by electrical applications to the head and neck. The treatment is usually very slow to yield a favourable result, but nevertheless it does prove successful in some cases. Erb has recorded a number of encouraging results, from his own observation and that of others.

Hysterical cases sometimes improve quickly under electrical treatment. Statical applications are perhaps the most suitable form of treatment for these cases.

It must not be forgotten that spasmodic affections are not infrequently reflex phenomena, thus there may be severe spasm of the muscles of mastication from inflammation about the gums or throat, and inflamed cervical glands sometimes cause wry neck. Or there may be spasm from direct irritation of the nerves, as in wry neck from disease of the cervical vertebræ. Before commencing electrical treatment a careful examination should be made for any source of irritation, and this, if possible, must be remedied.

In children, and also, though less commonly, in adults, wry neck may be due to exposure to cold or wet, and this form

has been called "rheumatic," and yields easily to simple measures.

225. **Writer's cramp.**—This is the best known form of a series of spasmodic affections which are produced by prolonged overwork of certain muscles, particularly when the work done is of a complicated and highly co-ordinated kind. The name of function spasm or occupation spasm has been given to this group. Besides those whose occupation is writing, violinists, piano-players, tailors and shoemakers, are subject to similar attacks in the muscles which they use most often. In writer's cramp there is spasm associated with muscular weakness pain and tremor, either of which may predominate; the chief seat of the cramp or palsy is in the intrinsic muscles of the thumb and first finger; if the occupation be persevered with, other muscles are called in to take the place of those which are deranged, and soon they also suffer.

The characteristic feature of these affections is that the weakness, or pain, or spasm, is produced only by one particular kind of work. The hand of a man with writer's cramp remains useful for everything except for writing, and so with the other forms of true occupation spasm.

The results of electrical treatment are unsatisfactory.

Max Weiss* in discussing the electrical treatment of writer's cramp recommends the use of constant currents of from two to five or eight milliampères, for fifteen to twenty-five minutes, with absolute rest from writing; applications twice daily during the first weeks, diminishing later to two or three times a week. Anode in the palm if extension is the main symptom, on the dorsum if flexion. Kathode to be placed on the nape of the neck, or on the upper and inner part of the arm. Anode may also be applied to the tender points for ten to twenty minutes. Treatment to the motor cortex should also be used, also to the spine at the lower cervical level.

226. **Tetany.**—This form of spasm, although not very common, deserves mention here, because of the peculiar increase in electrical irritability which forms one of its leading symptoms. There is also, as is well known, an increased irritability of the nerves and muscles to mechanical stimulation, and this is not confined to any particular nerve, although it has been most commonly observed in the facial nerve (facial irritability). The

* *Centralblatt fur die gessam. Therap.*, April, 1891.

peculiar spasms can be evoked by compression of a nerve trunk or of the main artery of a limb, or by a rough touch over a motor nerve. Erb* first showed that the electrical irritability was also increased in this disease.

In a recent paper Dr. Bernhardt† has reported three cases in which the electrical reactions were examined, his results compared with the normal irritability of the same nerves are represented in the following table, which gives the current in milliampères required to produce the first KCC contractions.

NERVE.	NORMAL.	TETANY. 3 CASES.
Facial	0·9—3 milliampères	0·5 —1·5 milliampères
Median	0·9—3·3 ,,	0·25—1·5 ,,
Musculo-spiral . . .	2 —5 ,,	0·25—1·0 ,,
Peroneal	1 —2 ,,	0·5 —1·1 ,,

ACC and KDT (kathodal duration tetanus) were also more easily produced than usual. In the electrical treatment of tetany the influence of the anode stabile is to be directed to the affected parts, and the current must be gradually diminished at the termination of the sitting to avoid the ill effect of sudden anodal opening. The results of treatment are said to be entirely favourable, but the disease is one which tends to disappear spontaneously.

227. **Exophthalmic goitre.**—Quite a large literature has grown up on the electrical treatment of this disease. Many favourable cases have been reported with various kinds of electrical treatment. So long as the pathology of the disease remains uncertain, the electrical treatment must continue to be tentative. It is by no means successful in all cases, although numerous cures have been reported in the journals.

It has been assumed that the seat of the disease is in the vaso-motor system, and especially in the cervical sympathetic. It is important to bear in mind, as has been pointed out by Gowers, that the sympathetic system is represented in the brain, and on this account the treatment should not be confined too strictly to the region of the neck.

* *Arch. f. psychiatric*, 1874.
† *Berlin Klin. Wochenschrift*, June, 1891, No 26.

In this country Cardew reported* a short series of cases where the constant current produced great improvement in the symptoms. In nearly all of them the frequency of the pulse-rate was reduced, the enlargement of the thyroid was diminished, and the nervous condition of the patient was improved. He suggested that the treatment should be carried out by the patients themselves three times a day, and also at other times if the palpitation of the heart should become severe. He advised that a current of two to three milliampères should be applied for six minutes; the anode to the region of the lower cervical spine, the kathode to the side of the neck (labile) from the mastoid process to the clavicle. The two sides of the neck should be treated alternately, and the patient should persevere with the treatment for two months at least. He also declared that the diminished resistance of the body, which has been observed in this disease, is due simply to the increased perspiration and moisture of the skin, and this opinion is now generally accepted.

Owing to this lowering of resistance a small electromotive force is sufficient to give the required strength of current. The number of cells in circuit must therefore be small, commencing with as few as three or four, and the galvanometer readings must be carefully attended to.

Induction coil currents applied to the neck have also been found efficacious.

Vaudey† has advised the electrolysis of the enlarged gland for the radical cure of this disease and reports a series of successful cases. His methods will be considered in a later chapter.

228. **Hemiplegia.**—In the less severe cases of hemiplegia good results are commonly obtained by electrical stimulation of the affected limbs, and this is a very valuable fact, because so little can be done in other ways to improve the condition of old hemiplegic patients. I have seen great benefit produced by the electrical treatment of such cases, and that not once or twice only, but frequently. In hospital practice the difficulty with old hemiplegic cases is rather to know when treatment may be discontinued, for as a rule the patients seem to wish to continue attendance indefinitely. Improvement up to a certain point is

* *Lancet*, July 1891.

† *Annales d'électrobiologie*, 1899.

the rule. After that continued treatment does very little. Much cannot be expected when there is well marked late rigidity. The series of cases recorded by Prof. Erb* seems to show that after an attack of hemiplegia the muscles may remain in a crippled condition from a sort of torpor of some part of the motor tracts, so that they remain for a time beyond the control of the will, although there may be no absolute interruption in the conducting paths. Thus a patient may at once recover much of his lost power after a single vigorous electrisation of his affected limbs. It is therefore very important that this treatment should always be tried in cases where a patient is recovering imperfectly from hemiplegia. Treatment should not be commenced until four or five weeks after the attack, in order to avoid all danger of setting up fresh changes in the brain, and it may be repeated three or four times a week. A certain number of patients will be distinctly improved thereby. Most of the improvement likely to be obtained in this way may be expected to show itself in the course of the first month. It is also advised by Erb and others that further treatment may be directed to the seat of the lesion in the brain, the continuous current being employed, the anode to the forehead and the sides of the head, and the kathode to the nape of the neck, the former electrode being slowly moved to and fro (labile) without interruptions; this direction of the current has been chosen on account of its following the course of the motor tract. A current of one to five milliampères is recommended, and the active electrode should be of medium size. This treatment is to be carried out daily for four weeks, the duration of each sitting being not more than five minutes. If aphasia is associated with the hemiplegia the anode may be applied to the region of the third left frontal convolution and island of Reil. I have no personal experience of the results of direct treatment of the brain in hemiplegia. As the morbid process in the brain is essentially a destructive one there must be limits to the amount of recovery which is possible. These limits will be determined by the extent and the situation of the damaged part.

* "Electro-therapeutics."

CHAPTER XIII.

The Spinal Cord and Nerves.

The spinal cord. Treatment of paralysis. Infantile paralysis. Progressive muscular atrophy. Injuries of nerves. Special nerve injuries. Neuritis. Neuralgia. Sciatica. Anæsthesia. Nerves of special senses.

229. **Electricity in nervous affections.**—Much time has been spent over attempts to arrest the degenerative spinal cord diseases by electrical applications, but hitherto without success. At the same time it is right that electricity should be tried in this class of disorder, for it may be that some day a successful method of electrically influencing the nutrition of the spinal cord will be discovered. The effect of electrical applications upon the brain and cord have not been very fully worked out up to the present.

During the past ten or twelve years I have received for treatment at St. Bartholomew's Hospital a certain number of cases of locomotor ataxy, of progressive muscular atrophy (Aran-Duchenne, Landouzy-Déjerine, Charcot-Marie types), of lateral sclerosis and of chronic myelitis, and have given them courses of electrical treatment with baths and sinusoidal current during weeks or months, or even in some cases during years. I have never been able to satisfy myself of a complete cure in any unequivocal case, although I have frequently thought that the progress of a case was temporarily arrested by the applications. For instance patients have often returned to ask for a further course of treatment as they had lost ground after its discontinuance ; this is often the case with myopathic atrophies. A few cases of early or doubtful tabes have appeared to have been cured. One patient sent as a case of pseudo-hypertrophic paralysis, and with symptoms closely resembling that disease, did recover completely, but the diagnosis was a little doubtful from the first. The class of cases above enumerated should therefore be considered unsuitable for electrical treatment of that kind in the present state of our knowledge.

It is quite different with cases of functional or slighter dis-

eases of the nervous system, with infantile paralysis, and with affections of the peripheral nerves. Among these disorders there are many cases which derive great advantage from electricity.

The sequelæ left by influenza, which sometimes produces symptoms of considerable mental and nervous failure, or even a definite neuritis with reaction of degeneration, are promptly relieved by electrical treatment; the same holds good for diphtheritic paralysis. In cases of severe alcoholic neuritis, the patients gradually regain power in the limbs and make good recoveries even after lying helpless for several months. Normal electrical reactions and good development returns in muscles which formerly showed wasting, paralysis, and a marked reaction of degeneration.

Whenever children are to be treated electrically great care must be taken not to frighten them at the commencement by sudden shocks; the current used must never be so strong as to alarm them or make them cry, and it is important that the apparatus used should work smoothly. Many coils are defective in the matter of contact breaker; until lately there has been little attention given to it, but there is a very great difference between a good and a bad one.

230. **Treatment of paralysis.**—Certain fundamental principles of treatment apply to nearly all cases of paralysis. If possible the seat of disease in brain, cord, or nerves, should be included in the treatment, as well as the paralysed muscles. The seat of disease is to be treated in the hope of setting up beneficial changes there, and the muscles are to be treated in order to maintain and stimulate their nutrition. Stimulation of the peripheral parts acts upon the central organs through the medium of the sensory nerves, and in a reflex manner may start motor impulses along the nerves to the paralysed muscles. When the paralysis is purely motor, and the sensory functions of the affected parts are normal, this reflex mode of stimulation is of importance, and it follows that peripheral sensory excitation of a limb in infantile paralysis, or of the face in Bell's palsy, is a rational procedure.

When a nerve trunk has been injured and repair is taking place, it is often noticed that voluntary power returns before the return of electrical reactions in the nerve and muscle. Sometimes too a muscle can be made to contract through its nerve earlier than by direct applications to its motor point. Here

direct treatment of the nerve trunk, by applying the electrodes to it above the seat of injury, or indirect treatment through the agency of reflex stimulation of its centre may prove useful. Erb says:—"A hindrance in the motor conduction, which cannot be overcome by the will, may perhaps be conquered by a stronger artificial stimulation, and the way thus made clear for voluntary excitation. Hence, if we allow the electric irritation to act energetically above the seat of lesion, the hindrance may perhaps be in this way removed."

When the battery current is used the paralysed muscles are to be treated by applications of the kathode, which must be well moistened and moved over the whole extent of the affected muscles; the current to be between five and ten milliampères, and the duration of treatment ten minutes. It is important not to use electrodes which are too small. A two-inch size is suitable, and produces less pain than smaller sizes, because the density of the current at its surface is less. If five milliampères should seem to be painful in the case of a child the current must be reduced; when the skin is well wetted the painful effect of the current is diminished. In addition to the labile applications the circuit may be opened and closed suddenly from time to time, or the current may be reversed occasionally for the sake of exciting contractions in the paralysed muscles. The indifferent electrode is to be placed upon the spine, or over the nerve trunk, in the neighbourhood of the lesion.

When the induction coil is used a similar method of application may be adopted, the current being carefully regulated so as not to produce discomfort. Or both poles may be applied to the affected part, one being buckled round the limb in a position close to the nerve trunk, while the other is manipulated over the muscles. If the muscles do not respond to the coil it is customary to use the current of the cells, although in such cases the induction coil may give results which are quite as good, or better. It must be remembered that the difference between the induction coil current and the battery current applied in a labile manner is only a difference in degree, one giving frequent and sudden variations of current, and the other infrequent and gradual variations. It must not be thought that cases with the reaction of degeneration derive no benefit from treatment by means of the induction coil.

The continually expressed opinion that for muscles showing

the reaction of degeneration the induction coil is useless is a mere belief only held by the inexperienced. The every day experience of those who are occupied with electro-therapeutics is completely against it. The results obtained by Duchenne from induction coil currents are a sufficient testimony to the value of this mode of treatment in all kinds of paralytic affections.

It is true that a muscle showing the reaction of degeneration will contract to the constant current only, and in so far as the contraction of the muscle is a good thing for the muscle, the constant current may be better than that of the induction coil; but it does not follow that the amount of benefit produced by the treatment can be measured by the amount of contraction set up in the muscle. It is said that electrical applications are useful to preserve muscles in good condition until their nerve has time to recover. This does not express matters quite correctly, for a muscle which is permanently cut off from its nucleus of origin will continue to degenerate and waste, quite irrespective of being made to contract by treatment with the constant current. The electricity is useful in such cases, after reunion of the divided nerve, to benefit the state of nutrition not only of the muscle but of the nerve, which must first recover before the muscle can begin to improve; and for its electrical treatment both coil currents and battery currents have their uses. This matter of the relative advantages and virtues of constant and interrupted current dates from a long way back. Each has been warmly advocated by its partisans to the exclusion of the other since the days of Duchenne and of Remak.

But in paralysis any form of electrical application is of value, mainly, if not entirely, as a means of stimulating the activity of the living tissues of the part under treatment; with the constant current of a battery the stimulation is chiefly obtained when the current is made to vary whether by interruptions or reversals, or by movements of the electrode over the surface, while with the coil the variations are produced in the apparatus. So far as the action of electricity upon the growth of muscle is concerned, the experiments of Debedat are valuable, as they indicate the principles to be followed in the treatment of paralysed muscles (§ 176).

In paralysed muscles it is often possible to notice the effects of fatigue after a very few contractions have been produced by

electrical stimulation. Sometimes two or three closures of the testing key suffice to fatigue a damaged muscle so much that its contractions cease to be apparent. From this one may learn to adjust the strength of current and the duration of treatment for different cases. Very short applications are sufficient for muscles in a feeble state; but they may be repeated at shorter intervals, say twice or three times daily.

231. **Infantile paralysis.**—There is no doubt that electrical treatment is of the utmost value for the development of muscles damaged by this disease. The task of treating the paralysis and atrophy which it so often leaves behind is long and difficult, but once a system of treatment has been instituted a gradual improvement soon becomes perceptible. From the result of an electrical testing which has shown seriously impaired reactions, many children have been thought to be beyond the reach of treatment, but it is quite certain that prolonged electrical treatment will do good to nearly all cases of infantile paralysis, particularly if not more than a year or two has been allowed to go by since the incidence of the disease. Even after that lapse of time something may still be done.

There is a formula in which the prognosis of infantile paralysis has been commonly summed up. It is as follows:—If the ganglion cells supplying the muscle are destroyed recovery must be impossible, and if the cells are not destroyed treatment is unnecessary, because the patients will get well of their own accord. This formula is widely accepted, because it saves such a lot of trouble, but I am sure it has done a great deal of harm. It starts from the assumption that the disease must either destroy all the motor cells of a muscle or else must leave them all uninjured, and this assumption is certainly not correct. On the contrary, the damage to the motor nucleus may be of any degree of severity or of any extent, and the paralysis may vary between slight weakness and complete loss of all motor power.

It is reasonable to suppose that a focus of disease in the anterior cornu of the cord may destroy some of the nerve cells of the nucleus of origin of a muscle, while others in the same nucleus may escape, and this might especially be the case if the nucleus of origin is an extensive one. On this point the statements of Sherrington are conclusive. In the *Medico-Chirurgical Transactions*, vol. 82, p. 456, he writes:—"The position of the

nerve cells sending motor fibres to any one skeletal muscle is a scattered one, extending throughout the whole length of the spinal segments innervating that muscle; in the limb regions many muscles receive their motor fibres from as many as three consecutive spinal roots, and the bodies of the nerve cells innervating those must, therefore, inside the cord, extend through the length of three whole segments of the cord as a continous columnar group, and in each transverse level of the cord these cells must lie commingled with nerve cells innervating many other muscles. Hence no traumatic injury of the spinal cord can ever paralyse a single muscle alone and apart from others."

This being so one can readily understand how a muscle may be crippled by poliomyelitis and yet may survive in part through the support of such of its ganglion cells as happen to have escaped destruction.

Duchenne long ago pointed out that a muscle crippled by infantile paralysis may still contain a few living functional muscle fibres, and that these may easily be overlooked in an ordinary electrical examination of the muscle, but that they can be successfully cultivated by persevering treatment. There is no doubt that cases admitting of similar interpretation do occur, for example, I have seen a quite respectably sized mass of calf-muscle develop in a limb which for two years at least had shown no trace of electrical reaction of any sort in that region. It is an interesting point that the new development of the calf just mentioned has taken place almost entirely in the outer head of the gastrocnemius. In another case in which the deltoid was paralysed and atrophied there now is good growth in its posterior third, and there only.

If the surviving fibres can by cultivation be made numerous enough to have some useful voluntary power, they will be able to maintain themselves in a way which is impossible to them if they are unable to do any work. I had an opportunity of testing and dissecting the muscles in an amputated leg the seat of severe infantile paralysis of old standing. The age of the patient was 20 years, and the limb had been diseased from childhood. The muscles of the leg were all extremely atrophied, degenerated and fatty; in fact, the calf was almost like adipose tissue, but still contained a sufficient number of normal muscle fibres to show visible contractions to the induction coil current. The other muscles of the leg, though in a state of advanced atrophy,

all contained some fibres which were able to respond either to the induction coil or to the battery current. These reactions showed that even at that time there must have been some surviving ganglion cells in the affected portion of the cord, and that a certain degree of trophic nervous influence was still available for the muscles of the paralysed limb. Its hopeless condition at the time of the amputation was the result, not only of the old attack of poliomyelitis, but also of the sixteen years or so of disuse, and it is probable that sedulous treatment by electricity, gymnastics and massage, would have enabled the limb to recover sufficiently for it to have been of some use to its owner.

The persistence for several years of a reaction of degeneration in cases of old infantile paralysis is a peculiar phenomenon, and implies, I believe, that the muscles showing it are not without some representation in their spinal centre. In cases of complete division of a nerve trunk, the muscles cease to react at all to electricity in a year or less, but in infantile paralysis a well marked reaction of degeneration may be demonstrated ten or twelve years or more after the original attack ; and this is a clear distinction between the condition of a muscle cut off completely from its nucleus of origin by section of its nerve, and a muscle paralysed and wasted by severe poliomyelitis.

Again a muscle which has been for a time without any kind of reaction may develop a reaction of degeneration at the time of its commencing recovery. This may occur after the reunion of a divided nerve (see § 235 for a case), or in poliomyelitis; and it also seems to suggest that there may be "trophic cells" as distinguished from purely motor cells and that in infantile paralysis the trophic cells may not always suffer in the same degree as the motor cells, and that fibres from the trophic cells may have a greater power of regeneration after injury than is possessed by the purely motor cells, and so may lead to the occasional restoration of modified reactions (RD) in advance of voluntary power or normal reactions, or even in the absence of them.

Among muscles damaged by infantile paralysis three degrees of injury may be noted. In one the muscles are wasted, but they present reactions which though weak, are normal in quality both to the induction coil and to the battery current. In the second group the muscles are paralysed, atrophied, and show

a reaction of degeneration, while the third group show no visible reactions at all.

It can be said of the first group that they tend to recover spontaneously, but if left to themselves recovery is slow and imperfect. Under treatment they usually advance rapidly, even when the affected limb has been left very thin and weak.

It is well known that muscles paralysed by poliomyelitis may recover spontaneously, but many remain in a state of imperfect recovery, even though their electrical reactions are normal, and these derive benefit from systematic electrical treatment. I have seen improvement start at once with treatment in a previously untreated case of fifteen years' standing.

With cases of the second class, namely, those with the reaction of degeneration, it is quite a mistake to say that they are incurable, and that electricity can do nothing for them. Electrical reactions of normal quality, and useful voluntary power may return in muscles which for a long time have shown RD and loss of voluntary power, and this I have seen a number of times.

In a child with a history of paralysis which came on at the age of 5 months, treatment commenced in June, 1891 ; she was then 3 years of age. There were no reactions in any muscles of either leg, there was extreme wasting, and marked talipes equino-varus in the left foot. She was quite unable to stand. After three years treatment her legs showed reactions to the induction coil in nearly all the muscles on both sides, and she could walk, though this was done in a rather awkward manner, because one quadriceps extensor muscle remained thin and weak. This case affords a clear instance of the good effect of electrical stimulation upon the nutrition of greatly enfeebled muscles, which at one time seemed to have fallen into the last degree of atrophy and paralysis.

I have notes of numerous cases in which normal reactions and voluntary power have returned in muscles long paralysed with RD.

The following illustrates the class of case :—

C. F., onset of paralysis in 1894, when seen in the same year there was RD in front muscles of right leg, with feeble normal reactions in the peronei, and no reaction of any kind in the calf muscles or in the tibialis posticus. Next year there was slight return of voluntary power. In 1899 voluntary power was much

greater, and there were normal reactions of good quality in the peronei and the front muscles of the leg, with the return of a reaction (RD) in calf and tibialis posticus.

The routine treatment with infantile paralysis should be as follows:—At the first examination the muscles are tested carefully and the result is recorded, the girth of the affected limb is measured, and the voluntary power of the paralysed muscles ascertained, and any faulty attitude of the limb noted. A note must also be made of the colour of the limb, its temperature, and whether chilblains or scars of chilblains are present or not. The mother or the nurse is instructed how to carry out a simple form of electrical treatment with a bath and an induction coil, and is further told to rub the affected limbs every night for a quarter of an hour. She must also be shown how to exercise the weak muscles by means of appropriate movements, and must take pains to make the child try to do its best to move the limb accordingly. If irons or other orthopædic appliances are worn the child is to be made to exercise its limbs without them for a certain time every day.

By impressing upon the parents the need for perseverance, one is able to ensure their co-operation, and this is the most important factor of all. The mother or nurse must also be taught how to manage and regulate the coil. The induction coil is the best instrument for use in these cases. In addition to the treatment in the bath a direct treatment of the weakest muscles by means of electrodes may be advised when the management of the case is in intelligent hands. Either the coil or the battery current can be used for this, as may seem most advantageous, and it is best that this part be reserved for the medical man's own application, because applications of direct current require medical supervision. Periodical testings and examinations must also be made to see how the case progresses.

The first signs of improvement are a better circulation in the affected parts, disappearance of chilblains and sores, and a gradual gain of voluntary power.

The return of electrical reactions comes later, and it is usual, when all contractility has been lost, for a weak reaction to the induction coil to return first. This means that the few latent normal fibres in the wasted muscle have begun to grow and to gain sufficient strength to produce a visible contraction.

When the lower limbs are the seat of paralysis, as is usually the case, the electric bath is an excellent method of applying the electrical treatment. An ordinary wooden tub of appropriate size filled with warm water is taken, the electrodes in the form of plates of metal are suspended at the two ends, and the child, dressed in a short waistcoat, is put into the bath in a sitting position. The current is then turned on and is very well borne in this way, and the whole extent of the paralysed parts comes simultaneously under treatment. The strength of the current is gauged by putting the hands into the tub, one at each end, and by watching the effect upon the child, the current being made weak at first, and strengthened gradually. It must not be so strong as to cause rigidity of the muscles. This plan requires no special knowledge of anatomy, it is efficient and likely to be persevered in, and this point of perseverance over long periods of time is the key to success. Even if only one of the lower limbs be affected, there is no reason why the bath should not be used, and if the sound leg be flexed and drawn up, most of the electrical current can be diverted into the affected one. From Debedat's observations (§ 176) one would advise that the current be interrupted rhythmically at intervals of one or two seconds. See § 82 for rhythmic interruptors.

The following summary represents the writer's views upon infantile paralysis:—

In every case of infantile paralysis which is not clearing up satisfactorily, it is important to apply electrical treatment, continuing it for six months or a year or more.

It is the exception for a muscle to be so completely destroyed by poliomyelitis as to be left without any functional fibres, and these remaining fibres can be cultivated by persevering stimulation of them.

Where the muscles show only the reaction of degeneration or even when reactions are entirely abolished, some improvement may be hoped for in a good percentage of cases.

The amount of restoration which is possible in a muscle will depend upon the number of surviving ganglion cells. With prolonged treatment recovery advances very much farther than one might expect, and is infinitely superior to the results obtained when treatment has not been given.

Even where the electrical reactions are not altered in quality, it is not good practice to leave the case to take care of itself.

In electricity we have a stimulating treatment, which is superior to any mechanical stimulation by rubbing or massage. It may advantageously be combined with these. The form of electrical stimulation to be employed is less important than the need for perseverance. As a rule the induction coil meets the requirements of the case, and when used in conjunction with the bath is quite easily arranged for use by the mother or nurse of the patient.

The distribution of the paralysis produced by acute anterior poliomyelitis is peculiar, and some muscles are affected very much more commonly than others.

In the first place the lower limbs are the seat of paralysis more often by far than the upper. In the lower limb the muscles of the leg are very frequently damaged, especially the peronei, the tibialis anticus, and the calf muscles ; the quadriceps extensor cruris is also rather apt to suffer ; and if the paralysis affect this muscle seriously, the whole limb becomes very much crippled thereby. Except when there is extensive damage to the limb the intrinsic muscles of the foot are likely to escape, and the same can be said of those of the hand.

In the upper limb the muscles of the shoulder and arm suffer rather frequently. The deltoid is often injured, and the loss of it cripples the arm very much ; moreover, it is a muscle which does not readily improve.

The deformities which result from the over action of muscles, when their antagonists are damaged by this disease, are well known. Many of the various forms of club-foot originate from infantile paralysis. It may be worth while to give briefly the action of the leg muscles upon the foot as summed up by Duchenne :—There are three pairs of muscles with the function of moving the foot upon the leg. 1. The calf muscles and the peroneus longus. 2. The tibialis anticus and the extensor communis digitorum. 3. The tibialis posticus and the peroneus brevis. The first pair extend the foot, the second pair flex the foot, and the last pair produce lateral movements.

The movements of flexion and extension by the first groups include lateral movements also, because the pull of the muscles is not direct. When simple flexion or simple extension movements are required, they are produced by the combined action of both components of each pair ; thus, the calf muscles extend and adduct, while the peronei extend and abduct, the tibialis

anticus flexes and adducts, the extensor communis digitorum flexes and abducts. Of the remaining pair, the one, the tibialis posticus, adducts, and the other, the peroneus brevis, abducts. There are many other composite movements carried out by these muscles, but individually considered their actions are those just mentioned. The special deformities likely to follow the paralysis of any of these muscles, or of any combinations of them, can be predicted, if their special action, and that of their antagonists, are borne in mind.

Some of these muscles play an important part in preserving the arch of the foot, and when they are paralysed a tendency to flat foot is well marked.

An opposite condition of exaggerated arch of the foot is also known, and was described by Duchenne under the name of *griffe pied creux*, or hollow claw foot. Sometimes it is an effect of paralysis of the interossei. These muscles flex the proximal phalanx and extend the distal phalanges of the toes by a single movement, they also produce lateral movements of the toes. Their action supplements those of the other flexors and extensors of the toes. The long flexors flex only the distal phalanges, while the extensors, extend only the proximal phalanx. In the absence of the antagonising action of the interossei the long extensors extend the first phalanges permanently, and the long flexors flex the second and third phalanges also permanently, and this produces a claw-like attitude of the toes. The abductor and flexor brevis of the great and of the little toes act in a similar way, and when they are paralysed the claw shape becomes more intensified.

The hollow claw foot or *pes cavus* is not very often developed as a sequel to infantile paralysis, if it does, it is generally unilateral. Cases of double *pes cavus*, from their history, and the associated symptoms seem to be probably due to spasm of the long flexors and extensors of the foot and not to paralysis of the interossei.

232. **Progressive muscular atrophy.**—Before considering he electrical treatment of this disease, it may be worth while to discriminate between the various states of muscular atrophy which have been formerly confounded under this name. These are "myelopathic" atrophies due to changes in the anterior cornua, "neuropathic" atrophies due to changes in the nerve trunks, and "myopathic" atrophies from changes limited to the

muscles themselves. True progressive muscular atrophy (Aran-Duchenne type) is a type of the first class, and pseudo-hypertrophic paralysis of the third, while various forms of atrophy due to neuritis require to be considered in the second class. Indeed the lines of demarcation between different groups have not always been drawn with precision.

The electrical reactions differ in the different forms of progressive muscular atrophy. In the myelopathic forms the gradual degeneration of the muscle, fibre by fibre, produces a condition in which some fibres may still react normally, while others respond only by a reaction of degeneration. Thus, it is sometimes possible to recognise in an affected muscle a quick contraction followed by a sluggish one, the latter being produced by the degenerated fibres and the former by those which are still sound. As the degenerated fibres soon waste away the final stage of an affected muscle is a stage of extreme atrophy, without any visible reaction at all.

In the type described by Dr. Tooth as the "peroneal" type, and also known as the "Charcot-Marie" type, it is possible to observe a reaction of degeneration in some of the affected muscles. In general, however, the muscles in cases of this type of atrophy show simple diminution to coil stimuli, and normal behaviour to cells. The diminution of response to coil currents ("faradism") may be extreme, and there is also diminution in the sensory perception of induction coil currents. As atrophy advances all reactions become increasingly difficult to provoke.

In the myopathic forms of atrophy the reaction of degeneration is not observed, and the only changes observed are quantitative (§ 187), simple decrease to coil and to cells being the rule.

In none of the diseases included in the general title of progressive muscular atrophy can it be said that the prospects of cure by electricity are good. Still in default of any other better method of treatment it is reasonable to believe that the use of electricity is a step in the right direction, and it is quite right that efforts should be made to obtain relief by means of electrical treatment. In the spinal forms Erb considers that he has seen relief, retardation, and even arrest of symptoms, especially in early cases, and advises treatment of the spinal cord. His method is to use the battery current, and to make the applications to the cervical spine, the cervical sympathetic, the lumbar enlargement and the peripheral nerves, treating particularly the

cervical enlargement, which is so frequently the seat of the most severe atrophic changes. Finally, the affected muscles are to be treated by the induction coil current, which should be moderately strong, though too vigorous a treatment is not advisable.

He adds that although electrical treatment may retard or arrest the progress of the disease, that yet it is in no way a cure, and that the successful results said to have been obtained are generally the consequence of errors of diagnosis, especially in cases of neuritis, infantile paralysis, and atrophy after joint affections. He considers myopathic atrophies to have a more favourable prognosis, as he has seen great benefit follow electrical treatment in long standing cases of that kind. Duchenne* states that by means of induction coil treatment he had been able to arrest the progress of the disease in an advanced case (which seems to have been undoubtedly one of "myelopathic" progressive muscular atrophy) to re-establish the power of the diaphragm, which had become seriously involved, to restore the bulk and vigour of an important muscle (the biceps), and to dispel the fibrillar twitchings, and that the recovery was persistent for several years, in spite of the fact that the patient returned to hard manual labour, a condition of things extremely likely in Duchenne's opinion to bring on a relapse. He is certain that he has seen an increase in the bulk of a wasting muscle from coil applications, but only in cases where the muscle had not altogether lost its irritability to coil currents. He lays down precise instructions for the method to be adopted as follows:—

1. To pass the moistened electrodes over the surface of each of the affected muscles, keeping them close together, and using a current of low electromotive force.

It is to be noted that Duchenne's regular practice in applying electricity was to use two small electrodes, both held in one hand, and moved over the surface of the muscle side by side.

2. To stimulate the muscles moderately, and with a current which is not interrupted very frequently.

3. To treat only the muscles which react to the coil, and to pay most attention to the most important muscles, and to terminate the sitting by a mild application to any muscles which may be threatened with an invasion of the disease.†

* "Elect. localisée," 3rd edit., p. 500, description and figure.

† For the muscles most usually attacked, see Duchenne, *op. cit.*, p. 494, or Gowers' "Diseases of the Nervous System," 3rd edit., p. 535.

High frequency treatment has been tried in progressive muscular atrophy, and Denoyés* has reported a case as being of this kind which was very notably improved by high frequency treatment so that the muscles increased in bulk, and normal reactions returned in the deltoid, biceps and the common extensor of the fingers of both sides, in all of which a reaction of degeneration had been observed at the time of commencing treatment. An examination of the details related by Denoyés suggests that the case should be regarded not as a true case of progressive muscular atrophy, but rather as an instance of an attack of poliomyelitis associated with the febrile illness which immediately preceded the appearance of the muscular atrophy and by which the patient was laid up for two months. The whole time from the onset up to the commencement of the electrical treatment was only seven months and the patient was seventy-two years of age. The reactions are also unlike those of the diseases grouped under the name of progressive muscular atrophy.

233. **Locomotor ataxy.**—The value of electrical treatment in this disease is not yet settled. At the same time it is certainly premature to dismiss electricity as useless in all stages of this complaint, although it is no doubt correct to say that in advanced cases of the disease electricity will not restore the tissues which have perished. A difficulty in determining the value of electrical treatment meets one at the outset in the natural tendency of the disease to become arrested in certain cases, particularly in those which come under treatment early. Another difficulty is that peripheral neuritis may be mistaken for locomotor ataxy.

Several of my patients, with very definite signs of tabes, have seemed to derive some benefit to their symptoms from a course of general electrisation by means of electric baths. In others the application of direct currents to the spine has seemed to be of service, and it is this mode of treatment which has generally been adopted. The electrodes are applied at the dorsal and lumbar regions. Many writers on electro-therapeutics have been able to bring forward instances of relief to symptoms from electrical applications in tabes. In the *Arch. d'électricité médicale* of 1893, the notes of thirty-seven cases are collected together from various sources by Dr. Laborde, and the whole subject of

* *Arch. d'électricité médicale*, March, 1901.

the electrical treatment of tabes is critically examined in a paper which forms a valuable contribution to the subject. His summary is that in his own experience the treatment of the spinal cord by direct currents does not cure tabes, but in certain cases it can relieve the pains, the ocular disorders, the weakness of the limbs, or even the bladder troubles. Induction coil currents seem to act unfavourably. A further study of the subject is desirable.

234. **Myelitis.**—Electrical treatment is certainly useful when, as the result of an attack of acute myelitis, a patient is left with weakness of the bladder or of the lower limbs. I have seen the systematic application of direct currents longitudinally along the spine produce very definite improvement in such cases. Thus in one case the patient, three years after the acute attack, could walk only with difficulty; his back muscles were so weak that he could not sit up for more than a few minutes at a time, and his sphincters were uncertain. He has so far improved under treatment as to be able to walk for several hours a day, to go shooting, and to play lawn tennis.

In his case the treatment has been by direct currents applied longitudinally along the spine. His man-servant was taught how to carry out the applications, which were given regularly for ten minutes daily. The improvement was slow, but has been continuous from the time when the electrical treatment was begun.

235. **Injuries of nerves.**—The student should consult a lecture by Sir Victor Horsley in the *Practitioner* for Aug., 1899. In injury and disease of the nerve trunks the natural tendency to recover is strong, and stimulation by electricity certainly hastens their recovery very much. It has been said of electrical treatment that the cases which do well under it would have done equally well if they had been left untreated, and this has often been made the excuse for the neglect of electrical methods. Even if this assertion were true, which it certainly is not, it applies with equal force to most of the drug treatments which medical men so complacently prescribe for their patients.

The following case illustrates the value of electrical treatment in a case of traumatic neuritis of the musculo-spiral nerve:—A gentleman, by sitting for a long time in one position in an arm-chair, compressed the musculo-spiral nerve, and numbness and weakness of the hand, with wrist-drop, was produced. There

was no treatment for several weeks, and there was no improvement. I was then asked to see him; he had paralysis with partial RD in all the extensors of the wrist and fingers; the supinator longus was also paralysed and there was impaired sensation over the back of the forearm and hand. The nerve trunk was tender to pressure at a point about half-way up the humerus.

Electrical treatment was commenced and at the end of a fortnight the patient had gained considerably in voluntary power and appeared to be on the high road to recovery. Electrical treatment was therefore suspended. He was instructed to rub the limb daily, and to exercise the muscles, and was told that he might expect the process of recovery to continue, even without further electrical treatment. A fortnight later he wrote saying that he had made no progress since the last electrical application. These were accordingly resumed, and improvement again began, and in another fortnight the patient was completely well.

The following instance of an Erb's paralysis is also instructive:—A man fell into a ship's hold in January, 1898, and paralysed the muscles of the upper arm. In the following year, March, 1899, he applied for relief, was seen and tested; a rupture of the 5th and 6th cervical cords of the brachial plexus was diagnosed, and an operation was performed for reunion. After the operation he disappeared from view for a time and did not return until November. There was no recovery of power. The limb hung helpless from his shoulder. He was referred to the Electrical department and a test showed a faint reaction of degeneration in the deltoid, biceps and supinator longus. In the previous March when tested before the operation there were no reactions at all in these muscles. It was judged from the return of these faint reactions (RD) that reunion must have taken place after the operation, and electrical treatment was accordingly commenced. Improvement began immediately. After three months he had gained enough to be able to use the limb for light work and recovery went on steadily afterwards.

For those who are not unwilling to be convinced these cases seem to offer satisfactory evidence that the electrical treatment played an important part in "curing" the paralysis, and answer the objection mentioned above, an objection which is not always

easy to meet, because for obvious reasons it is difficult to combat it by direct proof.

All those who have had practical experience in the matter have seen cases of nerve injury begin to recover rapidly under electricity after having been stationary for long periods of time under "expectant" treatment.

The simplest cases of peripheral paralysis are those which follow injury to the nerve trunks. These cases are common, and are sometimes of great interest from the exercise in applied anatomy which their diagnosis affords. The shoulder and upper limb are their most frequent seat. The chief causes of injury to the nerve trunks are contusions or lacerations, compression produced in various ways, and wounds with sharp instruments. Falls or blows upon the shoulder, and dislocations of the shoulder joint commonly produce paralysis of the muscles of that region. Pressure, as from the use of crutches or from the weight of the body upon the arm during sleep, often produces paralysis of the muscles supplied by the musculo-spiral nerve, and incised wounds of the forearm and wrist often lead to paralysis of the muscles supplied by the ulnar and median nerves. In all cases of this kind electricity is of great use, both for treatment and for diagnosis; and favourable results may be expected in almost all cases unless the nerve trunks have been actually severed, or are involved in cicatricial tissue. In that case surgical measures to unite the ends of the divided nerve, or to relieve it from its surroundings, are necessary before recovery can be expected.

From what has been said in § 191 it follows that injuries of nerves are likely to be followed by a reaction of degeneration in the muscles which they supply, and this does always follow if the injury to the nerve has been sufficiently severe. But, as such injuries may be of any degree of severity, it will be found that the reaction of degeneration is not invariably produced, for in the slighter cases the injury may be sufficient to impair motor and sensory conduction for a time without interfering with what may be called the trophic conduction of the nerve trunk. The partial reaction of degeneration is not uncommon in cases of nerve trunk injury.

In the examination of cases in which an injury to a nerve is suspected the anatomical details of the nerve supply must be carefully kept in mind.

The phenomena produced in cases of injury to mixed nerves are loss of motor power, and changes in the nutrition of the muscles and in their electrical reactions, with simple diminution of electrical excitability or partial or complete RD ; impairment or loss of sensation, pain, and vasomotor and trophic changes in the skin, which may show a patchy congestion or vesicles or bullæ, or may be more or less œdematous. The "glossy skin" of nerve trunk disease of long standing is well known, and easily recognised.

These changes in the skin signify irritation of the nerve trunk. In the upper extremity the skin of the hand and fingers becomes altered in colour and shiny, the finger ends become bulbous, and the nails defective. There is an alteration in the appearance of the wrinkles and folds over the knuckles, which can readily be recognised on comparing the affected with the sound side. The natural folds of the healthy skin tend to become obliterated.

It happens sometimes in cases of severe injury to nerve trunks that the paralysed muscles become hard and inelastic, and to the touch feel almost "wooden." This condition contrasts strongly with the flaccidity of ordinary paralysed muscles. It is probably an effect of interstitial œdema and signifies very serious damage. No reactions can be got from muscles in this condition, but an RD may be seen in them later, when the hardness has passed away.

236. **Neuritis.**—Electrical treatment is useful, not only in the paralyses which follow injuries of the nerves but also in cases of neuritis coming on in the course of disease.

The clinical importance of neuritis is much more commonly recognised to-day than it was a few years ago, thus fully justifying the words of Remak in 1860, when he wrote, "I am convinced that medical practitioners will soon recognise that neuritis is a pathological condition which occurs more frequently than is usually believed." At the present time the general public are beginning to adopt the word, so that they often now speak of their "neuritis," where formerly they would have spoken of their "rheumatism."

In the electrical treatment of neuritis the question of the choice of method turns largely upon the presence or absence of severe pain or of acute symptoms. Clinically one meets with cases of neuritis characterised by marked paralysis and little or

no pain, and again with others in which there is much pain but little or no paralysis. Pain felt in the nerve trunks is probably a pain due to implication of the nervi nervorum, and should be distinguished from pain felt in the area of distribution of the nerve, which indicates damage to the conducting fibres proper of the nerve trunk itself.

The presence of much pain in a case of neuritis is a contra-indication for brisk electrical stimulation, and when pain is marked the induction coil current is not so well borne as the sinusoidal current. In such cases the direct current, either in a bath or applied by electrodes, may be used at the commencement of treatment, with a change to the sinusoidal current and the bath, as soon as it can be borne with comfort. A point is soon reached when the latter form of current gives ease and relief, even though a good deal of pain and tenderness still exists in the limbs. In the paralytic cases the alternating current (coil or sinusoidal) is the best. Some writers would further divide the paralytic cases into two classes, namely, those showing the reaction of degeneration, with loss of coil reactions, and those in which coil reactions are not lost, and they would advise the battery current for the first of these and use the induction coil current for the latter class only.

If the neuritis is a general one, or is due to a general cause, even though its manifestations are local, the bath method of application should be chosen whenever it is to be had. Thus, the toxic forms of neuritis, as for example, neuritis from alcohol, arsenic, lead, &c., and neuritis following diphtheria, influenza, or other general infections can best be treated through the medium of the general bath. I have obtained the most satisfactory results in cases belonging to all these classes from the bath with sinusoidal current, and regard that form of application with the greatest favour. No doubt the general bath promotes the elimination of poisons in addition to its stimulating action upon the nutrition of the damaged tissues.

237. **Alcoholic neuritis.**—General applications by means of the bath and sinusoidal current are most convenient in the treatment of this condition. I have notes of several cases where the patients at the commencement of the treatment were quite helpless, and showed a marked reaction of degeneration in many muscles, in whom good voluntary power, normal reactions and well nourished muscles returned during the time of their

electrical treatment. It may be said of this disease, as of so many other forms of neuritis, that it has a natural tendency towards recovery, provided that alcohol can be withheld and the patient managed on general principles, but this does not in any way detract from the advantages to be derived from electrical treatment, which has a most distinct effect in promoting recovery.

Besides the typical cases of alcoholic polyneuritis one may often observe cases of a local neuritis in which alcohol is a predisposing cause or is acting prejudicially. Pressure palsy of the musculo-spiral nerve is chiefly observed in persons addicted to alcohol. The influence of alcohol in delaying recovery in cases of simple traumatic neuritis may also be commonly observed.

In other cases it may be difficult to decide whether a neuritis is primarily due to alcohol or to some other cause, as for example, gout, for both influences may be at work in the same individual.

238. **Gouty neuritis.**—What has been said of alcoholic neuritis and its electrical treatment, applies with equal force to gouty neuritis. The general bath method, the local bath, or finally, the direct use of the constant current in cases with much pain, may all be employed with advantage in gouty cases. The use of local baths with lithium salts dissolved in the water has been already referred to in §§ 155 and 212. The local treatment of a neuritis due to gout is likely to prove ineffective if the patient is allowed to continue in a general gouty condition, with recurrent articular attacks. On this account general electrical treatment is an important means even for a local gouty neuritis, and treatment by diet and by drugs must also be attended to. Some cases of "sciatica" are due to gouty neuritis, and a reaction of degeneration may be found in them if looked for.

239. **Rheumatic neuritis.**—The term "rheumatic" has been applied to facial paralysis coming on after exposure to cold, and to other instances where exposure to cold or wet has appeared to be the direct cause of a neuritis. Sciatica is probably in many cases a form of rheumatic neuritis. Neuritis of the circumflex nerve, the so-called "deltoid rheumatism" is another. The special methods of electrical treatment in these conditions will be dealt with under their respective headings.

240. **Neuritis from lead poisoning.**—In paralysis due to

lead the reaction of degeneration is usually present, and is an early symptom. The partial reaction of degeneration is also often seen in some of the affected muscles, and others may show only simple quantitative diminution. Erb has pointed out that from the long duration of lead paralysis and the frequently occurring relapses, the condition of the electrical excitability may be considerably complicated. In cases of long standing the reactions become very difficult to elicit. Treatment by electricity is of prime value, for muscles which have lost their electrical irritability almost completely may be seen to recover it under this treatment, which needs to be long continued to obtain good results. Although some writers have advised the constant current almost exclusively in lead cases, Duchenne long ago showed by practical trials that a cure can be effected by coil currents also. He stated that in lead palsy recovery will follow the treatment almost always, even if the irritability to the induction coil current has completely disappeared from the muscles.

For the ordinary type of case with double wrist-drop, the treatment usually employed by myself is the sinusoidal current, given by means of the arm-bath, with a rhythmic interruptor (§ 82) in the circuit. It is always followed by improvement, and recovery will be complete except in old broken-down patients where the affection is of long standing. In the more severe cases of lead poisoning the full length bath is to be preferred, and this may be combined with direct current applications to the worst muscles.

It is extremely important when the lead poisoning is a result of the patient's occupation that he should be advised to give it up altogether, otherwise relapses are almost certain to follow his return to work. When the patient returns to his occupation partly cured, he is almost certain to relapse.

To determine which of the extensors of the wrist are affected in cases of wrist-drop, the patient is told to raise the forearms and pronate them. If the muscles are all three of them paralysed there is then no power of extending the wrist at all. If the extensor carpi radialis brevior can act, extension of the wrist is possible when the fingers are first flexed. If only the extensor carpi radialis longior, or the extensor carpi ulnaris, can act, then slight extension is associated with a lateral movement to the side of the acting muscle. Although the supinator longus

usually escapes in wrist-drop due to lead, it does not always escape. The deltoid is sometimes affected. If the lower limbs are affected the peronei become paralysed.

241. **Arsenical neuritis.**—General neuritis may be produced by arsenic in medicinal doses or it may follow a single large dose. As an instance of the latter the following is of interest. A prison warder in Ceylon was poisoned by a dose of arsenic in May, 1896. He survived the immediate effects of the poison, although they were very severe, and six days later felt numbness of the extremities which extended until there was general loss of power. He could not stand, nor feed himself nor button his clothes. The bladder was not affected. In October he came to England and could then stand and walk a little. Knee jerks were absent, reactions showed partial RD in many muscles of the lower limbs. Upper limbs normal in quality. He was treated by general electrisation (sinusoidal baths) and slowly recovered. He is noted to have shed the nails of his toes several times during his illness.

A case of poisoning from arsenic given medicinally is the following:—A girl aged 10, with chorea, to whom arsenic had been given in ten minim doses for five weeks, became paralysed in all her limbs. The legs were most affected and the front muscles more so than the calf or peronei. RD was present. There was great wasting, some pigmentation of the skin and great pain in the limbs. She made a good recovery, the girth measurement of the calf increasing by two and a half inches between March and November.

Dr. Coleman* has reported a similar case, also in a girl of twelve years, who was treated for chorea with arsenic during a month, the daily dose being equal to forty-five minims of liquor arsenicalis. At the end of that time the chorea had ceased and the child seemed in good health, but a fortnight later she had complete paralysis of the extensors of the feet with RD, and partial paralysis of the extensors of the wrist and fingers with simple decrease but no RD. She recovered under the influence of rest, massage, and electricity.

Recently a correspondence in the *Lancet* has suggested that the treatment of extensive burns by picric acid may sometimes be followed by nervous symptoms, and in one case under treatment in the Electrical Department of St. Bartholomew's

* *British Medical Journal*, January, 1898.

Hospital an extensive brachial neuritis seemed to be due to the influence of this drug.

242. **Septic neuritis.**—The occurrence of a local attack of neuritis in the course of diseases which are apt to be associated with septic or sapræmic states, is not very uncommon. Cases have been described by numerous writers. I have myself seen one, probably of this class, in which a facial paralysis developed after confinement. Its symptoms differed in several points from ordinary "rheumatic" facial paralysis. It was associated with pain and numbness in the side of the face, and recovered very slowly and imperfectly. There was no exposure to cold and no ear disease or other local mischief to account for its coming on. Again, a patient who was being treated for stricture by the passage of catheters, was taken ill with fever for which he was admitted into Guy's Hospital. On his recovery he came to St. Bartholomew's Hospital with a paralysis of the right serratus magnus which had come on during his illness. He made a good recovery. This case I believe to have been a neuritis of septic origin affecting the posterior thoracic nerve.

Gonorrhœa has been recorded several times as a cause of neuritis. A recent case well reported, with many references, will be found in the *Arch. d'électricité médicale*, June, 1898, by Dr. Allard. The patient had loss of power in the lower limbs, impaired sensation in the same regions, with pain and tenderness of sciatic and crural nerves and showed great simple decrease to coil and to cells in the muscles of the legs, but no RD. The symptoms came on a fortnight after the appearance of a discharge, and were followed a few days later by inflammation in one ankle joint. The neuritis was treated by electricity. The patient recovered.

A form of neuritis which is very painful, and very slow to yield to treatment, is that which occurs in parts which have been the seat of suppuration, and is not uncommon after whitlows or poisoned wounds of the hand. The crippled condition which is left in these cases, though partly due to a matting together of ligaments and tendons, is also in part due to the existence of neuritis. Sometimes it is difficult to decide whether nerves may not have been divided in the incisions necessary for the evacuation of abscesses, and electrical testing should be called in for an answer. But although incisions may sometimes have divided some branches of the nerves and in

that way may have contributed to the paralysis, it is generally possible to show by electrical testing that neuritis exists in the areas of nerves which cannot have been injured by the knife. For example with an incision which seems to have been dangerously near the median or the ulnar trunk in the forearm or at the wrist, a testing may show that the corresponding ulnar or median muscles are damaged in unequal degrees. In such a case one could infer that there was no severing of the nerve trunk, and that the symptoms were due to something more distally situated. Again one may be asked whether the loss of power is due to an actual inflammatory process in the nerves, or whether it may not be due to compression of the nerves by cicatricial tissue. To answer this question one must look for signs of neuritis outside the area in which such cicatricial compression can be effective.

In painful amputation stumps we have another instance of septic neuritis, and in these cases there is often clear evidence of a neuritis extending upwards beyond the area of the scar.

The electrical treatment of these cases is slow. I have notes of several of them who have attended for a twelvemonth before completely losing their pains. Some relief is quickly felt from the applications, which are best carried out by means of the arm-bath with the sinusoidal current or the continuous current, the latter being perhaps superior to the former. Although the result comes so slowly it is none the less sure. Gradually the texture and aspect of the skin return to normal, the adhesions soften and the pain diminishes progressively and disappears.

243. **Neuritis from syphilis.**—Neuritis is sometimes met with in syphilis, and the following is a striking case:—A man came under treatment in December, 1892, with partial paralysis in the right arm. There was marked wasting of the biceps, and the grasp was much diminished in power. He had pains on the inner side of the arm. On his chest was an indolent patch of late syphilitic ulceration. In two months he had recovered, but not long afterwards he returned with sciatica, and a few months later came again with neuritis in the other sciatic nerve. In 1894 he reappeared with facial paralysis. Finally, in 1896, he came for the last time with hemiplegia. He was in a wretched condition and had been for several months laid up in a country infirmary.

It is difficult to estimate the value of electricity in syphilitic

neuritis because the drug treatment in this disease is of decided value. Electrical applications are probably useful, and should certainly be employed as an adjuvant in all cases.

244. **Neuritis after diphtheria, influenza, beri-beri, &c.**—These cases may show an extensive implication of many nerves or only a local neuritis. It is probable that in all of them the effect of general electrisation by means of the electric bath is useful, by reason of its effect upon the general toxæmic condition upon which they depend ; good results also follow local treatment when the neuritis itself is a local one. A neuritis following a specific infection will sometimes persist in the most obstinate way in spite of all treatment, although, as a rule, it clears up quickly and thoroughly.

Neuritis has been recorded after most if not all of the specific fevers. After typhoid fever a local neuritis is not very rare. It is possible that some of the slighter cases of local neuritis after severe illness may be of the nature of pressure paralysis or sleep paralysis (see § 255).

The electrical reactions in all these forms of neuritis vary between simple decrease of irritability and the complete reaction of degeneration. The latter is found in the more severe cases.

It may not be out of place to mention that neuritis is not the only nervous disorder which may complicate or follow the specific fevers. Hemiplegia or disease of the lateral columns or of the anterior cornua of the cord may also occur, and as all of these conditions are decidedly more unfavourable than simple neuritis, it is important to make sure of the diagnosis in every case.

245. **Peripheral paralyses.**—No subject is so closely bound up with electrical work as the diagnosis and treatment of the various kinds of paralysis which are caused by injuries or diseases of the peripheral nerves, and it will therefore be useful to consider in detail some of the types of peripheral paralysis most commonly met with in clinical practice.

246. **The ocular muscles.**—Their deep-seated position, the proximity of the retina, and the sensitiveness of the conjunctiva all help to make it practically impossible to excite contractions in these muscles by electrical applications.

For purposes of testing it has been proposed to use a fine electrode introduced into the conjunctival sac after that has

been rendered insensitive by cocaine. Good results have sometimes seemed to follow treatment by means of direct currents applied longitudinally through the skull, the kathode being placed upon the closed eyelid. Dr. Buzzard has recommended the use of the operator's index finger as the active electrode. Small sponges may also be used, as they are soft and readily adapt themselves to the surface of the eyelid. Dr. Buzzard has reported two cases where improvement followed the use of the direct current. Owing to the difficulties of satisfactory application electricity is not of much use in the treatment of ocular paralyses.

247. **Facial paralysis.**—This form of paralysis very frequently comes under electrical treatment.

Paralysis of the facial muscles may be the result of cerebral disease, as in hemiplegia, cerebral tumour or meningitis, but its most common cause is disease of the nerve trunk itself, and the part of the nerve which is usually at fault is that which passes along the Fallopian aqueduct.

In this part of its course a slight amount of swelling of the sheath of the nerve or of the lining of the bony canal is sufficient to produce compression of the nerve fibres and consequently a paralysis of the facial muscles. This is probably the explanation of the fact that facial paralysis is frequently seen in persons who are otherwise in good health. In many of these cases the onset of the paralysis can be attributed to some definite exposure to cold, and especially to a cold draught of air blowing upon the cheek, but in many others the history is by no means conclusive in this respect. A "rheumatic" tendency has been assumed as a predisposing cause. The common occurrence of facial paralysis is probably associated with this anatomical peculiarity of its course through a narrow bony canal, as any compression produced by congestion at that part of its course is likely, when once started, to lead to greater congestion for mechanical reasons.

As the severity of the paralysis in these cases will depend upon the length of time during which the nerve fibres are compressed, it is very important to endeavour to reduce congestion as early as possible. The application of blisters or leeches should always be attended to in cases of facial paralysis if they are seen soon after the onset.

Facial paralysis is often associated with disease of the ear,

and is then due to an extension of the inflammatory process to the Fallopian canal, or to the facial nerve itself.

The reaction of degeneration is present in a large proportion of cases of facial paralysis and the value of an electrical test for purposes of prognosis has already been referred to in § 192. Normal reactions may remain in mild cases. Partial RD and complete RD may each be observed in cases of this disease. Sometimes it happens that the reactions of the upper part of the face may differ from those in the lower part, showing an unequal degree of damage to the respective groups of nerve fibres. If the patient is tested daily from the commencement the gradual development of the RD will be clearly seen. As the reaction to the induction coil current may not disappear until the lapse of several days from the time of onset, a favourable prognosis cannot safely be given from a test made within that time. In testing a case of facial paralysis it is well to bear in mind that the skin of the face is sensitive, and that the muscles are near the surface, strong currents are therefore unnecessary, and must be avoided. Even in the worst cases of facial paralysis of the ordinary kind, due to exposure to cold, if progressive disease involving the nerve can be excluded, it is usual for recovery to take place eventually, and it is not uncommon for the recovery to take place unequally, thus the upper part of the face may improve faster than the lower or *vice versâ*. Old patients do not do so well as younger people. A considerable proportion of cases of facial paralysis occurs in young women ; they are excellent cases for study as they attend with the greatest diligence until completely recovered.

If a case of simple facial paralysis receives no electrical treatment its rate of recovery will be slower than if it be so treated. The cases of facial paralysis from ear or bone disease are naturally more unfavourable than those coming on from "cold." The hemiplegic cases usually recover fairly without treatment. Care must be taken to exclude all likelihood of the existence of unfavourable causes of the paralysis before making a favourable prognosis. All cases presenting unusual features are to be regarded with suspicion. Facial paralysis from disease of the motor nucleus of the nerve may occur.

The electrical treatment should be in accordance with what has been laid down for paralysis in general, viz. : direct treatment of the affected nerve and muscles, and reflex stimulation

through the sensory nerves of the skin of the face. For cases showing the reaction of degeneration direct current should be used. The indifferent positive electrode should be placed at the back of the neck, and the active electrode applied to the nerve and the muscles, each of the main branches of the nerves being followed in a labile manner from centre to periphery, and each muscle being treated with a few interruptions with the help of the closing key (fig. 44). Lastly, the skin of the face and the muscles may be treated with the induction coil. If normal reactions have not been lost, treatment with induction coil currents will be all that is required.

It has been proposed by Ballance and Stewart to remedy the deformity produced by permanent facial paralysis by an operation to connect the peripheral part of the facial nerve to a strand taken from the hypoglossal or spinal accessory.*

A " secondary contraction " of the facial muscles is often seen in cases of facial paralysis. Usually it shows itself during the course of recovery in the more serious cases. There may be a tonic contraction which shows itself in a narrowing of the palpebral opening on the affected side, or in a drawing of the angle of the mouth to the affected side, or there may be occasional twitchings in some of the affected muscles. Again there may be an associated action in the muscles so that movements of the eyelids occur when the muscles of the lips are set in action, and conversely the mouth may move when the eyes are closed. This secondary contraction in the muscles of the face has nothing in common with the " late rigidity " which appears in the limbs in cases of hemiplegia. It is the result of the original mischief which has caused the facial paralysis in the first instance. If this is only in part removed its presence may act as a source of irritation to the nerve and thus cause the tendency to spasm.

248. **The tongue and soft palate.**—Paralysis of the muscles of mastication is very rare. Injury or disease of the hypoglossal nerve may cause paralysis of the muscles of the tongue. Atrophy of one side of the tongue and a reaction of degeneration have been observed. The soft palate is occasionally paralysed, and its muscles may show a reaction of degeneration. If it should be required to test any of these muscles a small electrode should be used ; it may be covered by a layer of moist absorbent cotton, or it may be used uncovered.

* *Brit. Med. Jour.*, May 2, 1903.

249. **The trapezius and sterno-mastoid.**—Paralysis and atrophy of these muscles follow injury or disease of the spinal accessory nerve or of its nucleus. The trapezius, and sometimes the sterno-mastoid muscle as well, may suffer as a result of the suppuration of strumous glands in the neck, or of the surgical operations for their removal.

Paralysis of the sterno-mastoid is easily recognised if looked for. When the head is turned towards the opposite side, the outline of the muscle standing out under the skin is plain to see in health, but is lost if the muscle is paralysed.

FIG. 113.—Paralysis of left trapezius.

When the trapezius is paralysed there is a general feeling of weakness, and a complaint of myalgic pains about the shoulder, because the muscle plays so large a part in supporting the shoulder during the movements of the upper limb.

When one trapezius is paralysed the difference between the two shoulders can easily be recognised, particularly if the muscle be wasted as well. On the affected side the whole of the shoulder is lowered, and the line from the neck to the shoulder-tip is flattened. This difference is best seen with the arms hanging at the sides (fig. 113). The position of the scapula is changed, and the inner border of the bone does not

lie parallel to the vertebral column, as in health, but at an angle with it, its upper corner being rather further from the middle line, and its lower angle nearer, at a higher level and more prominent. Duchenne has explained why this is the case. The shoulder, having lost the support of the upper part of the trapezius, hangs suspended from the levator anguli scapulæ, and turning as on a pivot, at the point of attachment of that muscle, its lower angle is tilted inwards and upwards, and the acromion sinks downwards by the weight of the arm.

If the patient raises the arms to the head another peculiar

FIG. 114.—Paralysis of left trapezius. Clavicle seen from behind.

defect comes into notice; namely, that the clavicle in its outer half comes into view from behind. This is a valuable diagnostic sign of atrophy of the muscle (fig. 114).

Paralysis of the trapezius is often due to injury of the spinal accessory nerve during surgical operations on the neck. In one such case the incision was a small one, at the posterior border of the upper part of the sterno-mastoid. The nerve was accidentally divided, and the muscle became wasted, especially in its upper and middle portions. The clavicular part—the *ultimum moriens* of Duchenne—as well as the rest of the muscle, showed a marked reaction of degeneration. The lower part of the

muscle was not quite so much affected as the upper part, and the inferior angle of the scapula was therefore pulled downwards and not tilted upwards, as is the case when the whole muscle is paralysed. In another case the whole of the side of the neck was much scarred, as the result of numerous strumous abscesses and of the surgical treatment for their relief. Both the trapezius and sterno-mastoid on the right side were extremely wasted, and the rhomboids were also in the same condition. The scapula and clavicle were pulled forward by the action of the pectorals, and the wasting of the trapezius and rhomboids was very evident, for the contours of the ribs could be seen behind between the scapula and the spine.

The results of treatment in cases of paralysis of the sterno-mastoid and trapezius will depend upon the nature of the nerve injury. Where the nerve has been divided, especially if scar tissue is left surrounding the divided ends, the chances of a spontaneous reunion of the nerve are very small. A surgical operation for the restoration of continuity in the divided nerve should be tried, although it is doubtful whether this has ever been attempted.

Recovery has gradually appeared in some cases where there has been reason to believe that the nerve was divided, and in such cases it is probably due to regeneration of the nerve at its divided part. Electrical treatment should be energetically applied if there are reasons for hoping that the nerve is not completely divided, or if there are signs of returning power. In the other cases a surgical operation should be recommended.

250. **The serratus magnus.**—Paralysis of this muscle is interesting, because the deformity which results from it is peculiar. The serratus magnus is supplied by the posterior thoracic nerve, which rises from the fifth, sixth, and seventh cervical cords, and runs down the side of the chest behind the brachial plexus to reach the muscle. In the first part of its course the nerve runs in the substance of the scalenus medius muscle. The position of the nerve makes it liable to injury, especially in the side of the neck, and its independent course may explain the reason why paralysis of the serratus magnus is frequently seen without any other muscle being affected at the same time. Occasionally the nerve to the rhomboids comes off as a branch from the first part of the nerve to the serratus, and therefore the rhomboids may be paralysed with the serratus magnus.

The peculiar deformity which characterises paralysis of the serratus magnus is easily recognised if looked for. When the patient is examined with the arms hanging down, the shoulder may seem natural, but when the patient attempts to extend the arms horizontally in front of him, the movement is performed imperfectly, and the posterior border of the scapula on the affected side becomes prominent, projecting like a ridge from the level of the back (fig. 115). In a healthy person the scapula remains closely applied to the thorax during this movement; the function of the serratus magnus is to hold the scapula closely to the side of the thorax, and to advance it towards the

FIG. 115.—Paralysis of right serratus magnus.

front. When the arms are extended in front, the action of the deltoid tends at the same time to throw the scapula backwards, and this is resisted by the simultaneous contraction of the serratus magnus. If the deltoid be paralysed as well as the serratus, the patient cannot extend his arm horizontally, and the deformity due to the paralysis of the serratus, cannot be brought out in the way just mentioned. In this case, if the shoulder be pushed back while the patient is told to resist, it may be found that the posterior border of the scapula can be more easily displaced on the side of the paralysis.

Paralysis of the serratus magnus is not uncommon as a result of direct injury to the nerve in the side of the neck. The following example will serve as an illustration of the usual history of such cases:—A man was using an iron bar as a lever to move heavy weights along the ground, which he did by putting the end of the bar on his shoulder, and pushing upwards forcibly against it; he felt a pain, and soon afterwards he found that his shoulder began to "grow out." When he came under observation there was marked paralysis of the right serratus magnus, and the rhomboids were also affected, which made the characteristic deformity of the shoulder even more pronounced.

Paralysis of the serratus magnus may occur as part of an extensive injury to the region of the shoulder. In two cases of which I have notes the patients had suffered severe injuries, one having been crushed in a lift accident, in which he broke his forearm, and the other having been hurt by a heavy packing case, which fell upon him. Both of these, in addition to other injuries, had paralysis of one serratus magnus—the right. Indeed, all the cases of paralysis of the serratus magnus from injury, which I have seen, have been on the right side, and in male patients.

Paralysis of the serratus magnus is by no means uncommon as a result of neuritis, quite apart from injury. Cases have been recorded after many of the specific fevers, and the figure shows a case in which it came on after an illness, presumably of a septic nature (fig. 115). An instance in which this form of paralysis followed small-pox is described and well figured in the *Journal of the Royal Army Medical Corps*, April, 1904.

Cases due to injury or disease respond well to electrical treatment, unless the nerve is actually divided; division of the nerve is not often met with.

In testing and treatment the indifferent electrode is placed in the posterior triangle of the neck, and the active electrode is applied to the serrations of the muscle.

The notion is sometimes entertained that the peculiar position of the shoulder-blade, described above, is due to dislocation of the latissimus dorsi from its position at the angle of the scapula. This view is erroneous.

251. **The rhomboids.**—These are supplied by a special nerve, which comes off from the fifth and sixth roots, either separately or in conjunction with the posterior thoracic nerve.

In common with the other muscles whose nerves run a somewhat exposed course in the neck and shoulder, the rhomboids are liable to paralysis from injury. It is not usual to find them affected alone. When they are paralysed the posterior border of the scapula is less firmly placed than in health, and the fingers can be introduced under the edge of the bone more easily than usual. If the trapezius be well developed, it is not very easy to make out the paralysis of the subjacent rhomboids by electrical testing.

252. **The scapular muscles.**—The supra- and infra-spinati are often paralysed as the result of blows upon the shoulder, though less frequently than the deltoid.

When the spinati are wasted, the spine of the scapula becomes prominent, and the muscles themselves can be seen to be diminished in bulk. The patient is unable to perform external rotation of the humerus in a proper manner if the infra-spinatus is paralysed; and the other external rotator of the humerus, the teres minor, is often affected simultaneously, though supplied by a different nerve. The movement of external rotation is necessary in writing for moving the hand across the paper, and in sewing, the same muscles also come into play.

The nerve (supra-scapular nerve) which supplies the spinati is exposed to the risk of injury, owing to its superficial position on the shoulder. The supra-spinatus is a less important muscle than the infra-spinatus, and its condition is not so easy to determine, because it is thickly covered by the trapezius, which makes electrical testing of the muscle difficult, and its functions as an elevator and a weak internal rotator of the humerus can be performed by the deltoid. When the infra-spinatus is paralysed, it is probable that the supra-spinatus is in the same condition.

The internal rotators of the humerus, namely, the sub-scapularis and teres major, have a nerve supply (the sub-scapular nerves), which escapes injury much more often than the spinati; and the same may be said of the latissimus dorsi, which is also supplied by a branch from the brachial plexus, viz., the long sub-scapular. The pectoralis major and minor also escape as a rule.

There is no special point to note in the electrical testing and treatment of these muscles. Usually they are affected with the deltoid and their treatment is similar to that which is employed for the latter.

253. **The deltoid.**—Paralysis of this muscle from blows upon the shoulder or dislocation of the shoulder-joint, is one of the most common forms of paralysis in the upper extremity.

The circumflex nerve is exposed to injury in its course through the muscle, and its trunk may also be strained in dislocations, or it may be compressed by a crutch or axillary pad. The teres minor suffers with the deltoid when the injury is to the trunk of the nerve; when the injury is in the intra-muscular part it may escape. It is not always easy to determine the state of the

FIG. 116.—Paralysis of right deltoid.

teres minor by electrical testing, as it is so much covered by other muscles, nor by observing the voluntary movements of the patient, as its functions can be adequately performed by the infra-spinatus. The attempt to ascertain its condition, however, should always be made.

The spinati are often paralysed by the injury which paralyses the deltoid.

The flattened appearance of the shoulder, and the prominence of the acromial process of the scapula make it easy to recognise

paralysis of the deltoid, unless the subject be very stout. In infants especially the adipose tissue which covers the shoulder may mask the wasting of the muscle. When the wasting and paralysis are extreme the head of the humerus is no longer held up in the glenoid cavity, but can be seen and felt to hang loosely in a state of partial dislocation, and to be freely moveable in its socket. One may even be able to push the tip of a finger between the acromion and the head of the humerus.

When the deltoid is paralysed the arm cannot be raised to the horizontal position, and the utility of the limb is very seriously diminished for a very large number of movements, as no other muscle is able to supplement its action to any appreciable extent; the supra-spinatus, which has a similar function, is too feeble to be able to raise the weight of the arm. It sometimes happens that part only of the deltoid is paralysed; I have notes of three cases. In one the patient had had suppuration round the shoulder, and an incision for the evacuation of the pus was made on the posterior aspect of the joint. One of the branches of the circumflex nerve was injured, and the posterior half of the muscle was wasted, and showed a partial reaction of degeneration, while the anterior part reacted naturally.

Traumatic paralysis of the deltoid is very common. Recovery is the rule in the majority of the cases, but there is a considerable minority which do not improve at all satisfactorily, and on this account it is wise to express a guarded opinion when there is much wasting and a reaction of degeneration, and the prognosis must be made to depend upon the behaviour of the muscle under treatment. In elderly people particularly, the progress of recovery is very slow, and six months or more may pass before much improvement is visible. If the electrical reactions are normal, or show only a quantitative change, or show the partial reaction of degeneration, with some preservation of induction coil reactions, the prognosis is more favourable. Taken generally, the deltoid may be said to be a muscle which is easily damaged, and has not a very great recuperative power. The presence of articular changes in a case of paralysis of the deltoid is very common, as both muscle and joint are supplied by the circumflex nerve, and both suffer when the nerve is injured. Adhesions in the joint should be treated by mechanical means after the nerve has recovered its functions. If the adhesions are broken down before the muscle and nerve are restored they

are very likely to form afresh. The skin over the deltoid receives sensory fibres from the circumflex nerve, and loss or impairment of sensation is frequently to be found if looked for when the muscle is paralysed.

254. **The muscles of the arm and forearm.**—The musculo-spiral the median and the ulnar nerves are often injured in their course in the arm and forearm. The usual causes are incised wounds, implication in callus or scar tissue, contusions, pressure from bandages or splints too tightly applied, or pressure from the use of crutches, or from lying or sleeping with the weight of the body resting upon the limb. Pressure palsies affect more especially the musculo-spiral in the upper arm; while the ulnar and median suffer more particularly from incised wounds, and in the forearm. In all cases of paralysis affecting the upper limb it is important to make a careful test of the reactions of the muscles, in order to determine the situation of the lesion, its severity, and above all, to ascertain whether a nerve is likely to have been severed or not. If it is severed the question of an operation for reunion of the divided ends must be considered. Paralysis from the pressure of splints and bandages is sufficiently common to be of importance, and though fortunately it is not usual for injury produced in this way to cause permanent harm, yet sometimes it does do so. I have notes of many cases in which there was little or no doubt that tight bandaging had caused paralysis. Thus in one patient who received an incised wound involving the median and ulnar trunks it was found, when the wound had healed, that he had developed a paralysis of the musculo-spiral as well. Paralysis from tight bandaging is seen with especial frequency among persons who have received injuries when far away from skilled assistance, and have had their injuries bound up tightly and left so, until medical assistance could be reached.

In all cases of injury to nerves, except when the nerve is severed, electricity should be used for purposes of treatment. Arm-bath methods (§ 154) are of great convenience for injuries at or below the elbow, but good results are also obtained by direct applications. The coil or sinusoidal current may always be used, and in cases with RD the battery current should be used in addition.

255. **The musculo-spiral nerve.**—Paralysis of the muscles supplied by this nerve is characterised by the presence of wrist-

drop; usually the extensors of the wrist and fingers and the supinator longus and brevis are involved; the triceps may either escape or may be involved according as the injury is high up in the arm or not.

Musculo-spiral paralysis from pressure on the trunk of the nerve during sleep is extremely common, at least among hospital patients.

The usual history is that the patient goes off into a heavy sleep, from which he awakes with his hand and forearm powerless. Often the patient has slept while sitting at a table with the head resting on the arm, or with the arm hanging over the back of a chair; in either case the musculo-spiral nerve trunk has been pressed upon. It does not often follow sleep in bed. Almost always the patient has been under the influence of alcohol and has slept very soundly. Otherwise the discomfort felt in the arm would have been likely to awake him before the production of more than a transient paralysis Nearly all the cases are in intemperate persons. The predisposing effect of intemperance is well shown in the following case:—A potman after sleeping for two or three hours developed a pressure palsy of his left musculo-spiral nerve. This got better, but in the following year he injured his ankle and was obliged to use a crutch. This brought on another attack of musculo-spiral palsy before he had used the crutch more than ten days.

Slight degrees of temporary paralysis from pressure on a nerve-trunk during sleep are familiar to most persons. To notice a numbness or a feeling of pins and needles in one arm on awakening from sleep is not uncommon, especially among those who are in a poor state of health.

Pressure paralysis has been thought to be secondary to compression of the blood-vessels of the limb, producing anæmia of the nerve, but if this were the case the paralysis should not be confined to the region of one particular nerve trunk, as is the rule if it were due simply to anæmia of the limb from compression of the main artery. It would rather be expected to involve chiefly the distal parts, irrespective of the nerve supply.

A case of a pressure palsy in the leg, which came under my observation some years ago, shows that it is the nerve itself which suffers from compression. In that case the pressure was on the great sciatic nerve at the back of the thigh, and there could not have been any compression of the femoral artery.

The patient was a young man who attended a meeting, and in order to have a better view of the proceedings he sat for an hour upon the back rail of his chair; at the close of the meeting he found his leg numb and helpless, and was assisted home. Two days later he came under observation. He had paralysis of all the muscles below the knee. He recovered in a fortnight under treatment by rubbing and the induction coil current.

Sleep palsies are almost always limited to the musculo-spiral nerve.

In crutch palsy too it is usually the musculo-spiral nerve alone which is paralysed, but the circumflex nerve, or the ulnar or median may also be involved. Sleep palsies are always unilateral; crutch palsies may be double if two crutches are used, they are usually more marked on the side of the injured leg.

The degree of impairment of sensation varies much; as a rule there is some complaint of numbness on the back of the forearm and hand, and some anæsthesia may be detected.

Paralysis of the extensor group from lead poisoning has been already referred to. Fractures of the humerus may cause extensor paralysis from injury to the trunk of the musculo-spiral nerve by the broken bone, or the nerve may be implicated in the callus thrown out around the fractured points.

A rare form of extensor paralysis is one which affects the special extensors of the thumb. I have twice seen a paralysis of these muscles, with a reaction of degeneration, in cases without any history of previous injury.

All these forms of extensor paralysis vary considerably in severity. Those in which the electrical reactions are not much impaired may recover in ten days or a fortnight. When the reaction of degeneration is present the duration will be longer, and may last for more than three months. Recovery can be confidently expected in uncomplicated cases, where the pressure has not lasted very long, and it is certainly promoted by electrical treatment. I have often seen improvement start at once on the commencement of electrical treatment, after weeks had been wasted in vain in the expectation of spontaneous recovery. It is probable, however, that even in these the paralysis would go away of itself in time, but this does not prove that electrical treatment is unnecessary.

When the pressure is due to the use of crutches they must either be given up, or if that is impossible the head of the crutch

must be well padded, and the state of affairs must be explained to the patient so that he may be able to co-operate; crutches with handles which can be grasped in the hands are the best, for with them the patient can transfer part of his weight from the arm-pits to the wrists. The crutches should be attended to before they have produced paralysis.

256. **The ulnar and median nerves.**—These nerves are frequently divided at or near the wrist by incised wounds; a very large number of the cases being from cuts caused by broken glass. It is not uncommon for both nerves to be divided in one accident, and if the ends are not re-united when the wound is first dressed, wasting and paralysis of the intrinsic muscles of the hand is the result.

When the ulnar nerve has been completely divided near the wrist the symptoms produced are:—1. Paralysis with wasting and the reaction of degeneration in the hypothenar eminence, in all the interossei, in the two ulnar lumbricales, and in the adductor and flexor brevis (inner head) of the thumb. After a time the deformity known as the "clawed hand" is produced. The palm becomes thin and flat, the heads of the metacarpal bones and the flexor tendons in the palm become unduly prominent, the proximal phalanges are over-extended, the distal phalanges are permanently flexed. This is the result of the paralysis of the interossei. These muscles flex the proximal phalanges and extend the distal ones; and so balance the movements of the fingers, which are performed by the long flexors and extensors. If the interossei are paralysed the unbalanced action of the long extensors and long flexors produce the characteristic deformity. 2. Sensation is impaired or lost in the little finger, in the ulnar half of the ring finger both front and back, and in the corresponding part of the palm of the hand. 3. Trophic changes are sometimes produced in the skin and finger nails of the anæsthetic area, often with œdema; the temperature of the part is lowered, and sometimes there is very severe pain of a burning character, to which the name of "causalgia" has been given. When it exists the temperature is raised above that of the opposite side, and the patient experiences a sensation of heat and seeks for relief by cold applications. These trophic changes signify an irritative lesion, and are not found from simple division of the nerve trunk.

After division of the median nerve at the wrist the conditions

are different, the clawed hand which is so characteristic of the divided ulnar nerve is not present, and the chief feature is the wasting of the thenar eminence, and the everted or ape-like thumb, which lies with the nail facing dorsally; the abductor, opponens, and outer head of the flexor brevis of the thumb are paralysed, atrophied, and show the reaction of degeneration. There is loss of sensation in the thumb, index, middle, and half the ring fingers, and in the corresponding part of the palm, and of the two distal phalanges of the same fingers on the dorsum of the hand.

257. **Combined paralyses of the upper limb.**—It may happen that muscles supplied by more than one nerve trunk may be paralysed together from injury or disease. After dislocation of the shoulder, and particularly when a dislocation has remained for some time unreduced, there may be complete paralysis of the whole limb.

Several causes combine to produce extensive paralysis after a dislocation. In dislocations forward the head of the humerus presses upon the brachial plexus below the coracoid process, and so produces paralysis below that point; but this pressure will not cause paralysis of the muscles of the scapula, for these are supplied by branches given off higher up, and yet they are generally, if not always, implicated. It is said that the upper cords of the plexus may be compressed between the clavicle and the vertebral column if the violence has tended to drive the shoulder backwards, for the shoulder has free play at the sterno-clavicular joint, and might be driven sufficiently far back to produce such compression. The upper cords of the plexus may be directly subjected to traction from the injury, or finally they may be damaged by the efforts employed in reducing the dislocation.

It seems probable that the commonest cause of injury to the upper cords of the plexus is a stretching force acting either at the time of the injury or in the efforts to reduce the dislocation; while the muscles of the forearm and hand are paralysed from the pressure of the dislocated head of the bone upon the lower cords subsequently. Severe injury to the shoulder may cause rupture of the nerve roots which form the brachial plexus. When the spinal nerve roots are torn there may be laceration of the fibres which emerge from the thoracic cord to supply the cervical sympathetic, and the pupil on the injured side may be

contracted in consequence. Mr. Bowlby* has published several cases in which this has been observed.

258. **Root paralysis. Erb's paralysis.**—Paralysis of muscles caused by injury or disease of the roots of the brachial plexus has been called "radicular paralysis" or "root paralysis." The grouping of the affected muscles in "root paralysis" will depend upon the representation of the muscles in the different spinal nerve roots which go to make up the brachial plexus, and will not correspond with the grouping according to nerve trunk distribution. It is evident that electrical testing may be of prime importance in distinguishing between paralysis due to nerve trunk lesions and those caused by lesions of the nerve roots.

One particular type of root paralysis affecting the muscles of the shoulder and arm has received the name of Erb's paralysis, though in France it is often known as the Duchenne-Erb type, because Duchenne first drew attention to it in 1867, and reported five examples. It was Erb who, in 1874, pointed out the anatomical reasons for the special grouping of the paralysed parts. Erb enumerates the affected muscles as the biceps, coraco-brachialis, and brachialis anticus, which are supplied by the musculo-cutaneous nerve; the deltoid supplied by the circumflex nerve; and one muscle supplied by the musculo-spiral, namely, the supinator longus; sometimes the spinati too (suprascapular nerve) are involved. The affection of the supinator longus alone among the muscles supplied by the musculo-spiral nerve might seem at first to be a perplexing feature, but it is easily explained on the ground that the injury is situated above the point at which the musculo-spiral nerve is built up. Compare the condition in wrist-drop from lead, in which the supinator longus may escape when the rest of the muscles supplied by the musculo-spiral nerve are paralysed. Erb pointed out that an injury limited to the two upper roots of the brachial plexus, the fifth and sixth cervical, or their combined trunk, would produce the kind of paralysis under consideration; and further showed that these cords can be directly stimulated at a point in the neck, one inch above the clavicle and a little external to the outer border of the sterno-mastoid. This is known as Erb's motor point, and by means of an electrode applied to it the group of muscles in question can be readily thrown into simultaneous contraction (§ 183).

* "Injuries and Diseases of Nerves," London, 1889, J. and A. Churchill.

The existence of Erb's paralysis as a clinical unit depends upon the comparatively exposed position of these two nerve roots, just as we have seen that paralyses of some of the single muscles of the shoulder are common for the same reason, and varieties in the extent of the paralysis exist according as the injury or disease affects chiefly the fifth or the sixth roots or their united trunk, or extends into the seventh.

From what is known one would expect that a lesion of the fifth and sixth roots, or of their combined trunk, should involve not only the muscles already mentioned, but also the rhomboids, the teres minor, the subclavius, and the upper parts of the pectoralis major and serratus magnus, and the supinator brevis, and most of these muscles have been noted as involved in some of the recorded cases. When they escape it must be due to their partial representation in one or more of the other nerve-roots of the brachial plexus.*

It must be borne in mind that Erb's paralysis is not a special form of disease. The name signifies the paralysis of a special group of muscles. Any sort of injury or disease which affects this special part of the brachial plexus will produce paralysis of the group of shoulder and arm muscles already mentioned. Traction on the arm of a child during difficult labour is a common cause of Erb's paralysis so that Duchenne described it as "obstetrical" palsy of the arm. Among twenty cases of which I have notes, seven were caused in this way, four followed direct injury, one was due to sarcoma of the cervical vertebræ, but, from the extension of the disease, the paralysis was not long limited to the muscles of the Duchenne-Erb group. One was associated with an abscess in the neck, and the remainder came on gradually and were due to neuritis of some kind.

All degrees of combined paralysis from the typical Duchenne-Erb type to complete paralysis of the shoulder and arm may be met with.

The triceps in some cases and the extensors of the wrist in others, have been noted to be weak in cases of Erb's paralysis. In two cases I have noted some weakness of the upper part of the pectoralis major.

Wilfrid Harris and Warren Low believe that the characteristic lesion of Erb's paralysis is situated in the fifth cervical

* For much important work upon these and associated matters, see Sherrington, "The Spinal Animal," *Med. Chir. Trans.*, 1899.

root, and not in the common cord formed by the junction of the fifth and sixth, and they further state* that they have found the pronator radii teres and the radial extensors of the wrist to be involved in association with the other muscles generally affected in Erb's group.

There is a certain amount of variation between individual cases, so that we cannot state absolutely that certain fibres run always in the fifth root, and certain others only in the sixth or seventh. Moreover many, or most of the limb muscles, receive their nerve-supply by roots emerging at more than one level; for example, the serratus magnus from the fifth, sixth, and seventh cervical roots.

259. **Other root paralyses.**—It is not very unusual to see other forms of paralysis in the upper extremity, in which the distribution corresponds rather with the spinal nerve roots than with the individual nerves of the upper limb. Klumpke's paralysis is due to an affection of the lower roots of the brachial plexus, and may be associated with ocular symptoms from implication of the roots of the cervical sympathetic.

The cases described by Lewis Jones† of atrophy of the intrinsics of the hands in young persons may be assigned a similar position as cases of root paralysis from disease of the first dorsal spinal root. The characteristics of this group of cases are well marked. They usually show atrophy of the intrinsics of one or both hands, the median and ulnar muscles are affected together, although the muscles in the forearms supplied by these nerves may escape. A reaction of degeneration is often present and pain is generally complained of. Usually it is not severe, and it is referred to the area corresponding to the first dorsal sensory root. Complete recovery is not the rule, though partial recovery has been noted in about half the cases. Similar atrophies with a distribution corresponding to the intermediate spinal nerve roots of the brachial plexus may be observed more rarely.

260. **The lower limb.**—Cases of paralysis from disease or injury of the nerves of the lower limb are much less common than they are in the arm. I have notes of only a few instances. In one recorded case there was paralysis of the front leg muscles from the pressure of a leather pad upon the peroneal nerve just

* *Brit. Med. Jour.*, Oct. 24, 1903.

† *St. Bartholomew's Hospital Reports*, 1894.

below the head of the fibula. The patient was a man who walked daily upon stilts which were strapped tightly round the legs just below the knee, and so set up the pressure upon the nerve.

Other cases may follow injury about the knee-joint, gunshot wounds of the thigh, or fractures through the lower third of the femur, and the operation for the relief of genu valgum may cause injury to the nerve trunks. The most usual seat of the injury to the nerve trunks of the lower extremity is in the external popliteal nerve or the peroneal nerve. This was the case in the following instances:—The pressure occurred during occupation. In one, a carpenter sat on the ground with one leg doubled under him; in the other, a leather sewer fixed her work against the under side of a table, holding it there by the upward pressure of the left knee against the outer side of the right knee which was crossed over the left one. In both there was pressure upon the peroneal nerve.

Cases are met with occasionally in which symptoms occur resembling those of a peripheral neuritis, but due to a central lesion in the spinal cord. The presence of increase in the knee jerks, and the incomplete limitation of the symptoms to a single branch of the sciatic nerve, should be taken as signs that such a form of paralysis is central and not peripheral. The results of treatment in these cases are not good, whereas with strictly peripheral cases they are generally satisfactory.

261. **Pes cavus.**—This has already been noticed under the heading of infantile paralysis. It is often present in diseases which lead to muscular atrophy, and then signifies a paralysis of the interosseal muscles. But in many cases of pes cavus sent for electrical testing the reactions of the interossei are found to be unaltered, and the deformity appears due to spasm of the long flexors and long extensors rather than to weakness of the intrinsics of the foot. Cases of this kind are not uncommon and are seen in young persons, with a history of gradual onset, whereas in cases of poliomyelitis the onset is generally a sudden one. Both sides are involved. When the knee jerks are increased and the leg muscles are large and firm, and the interossei give normal reactions the cases clearly are not due to poliomyelitis and correspond best to the descriptions of primary spastic paraplegia. In these cases electrical applications do no good.

262. **Anæsthesia.**—The treatment of anæsthesia is similar

to that used for paralysis (§ 230). The cerebral anæsthesia which sometimes occurs with hemiplegia is usually not permanent, and it may very often be made to disappear by a few induction coil applications to the affected areas. Hysterical anæsthesia may also be dispelled in the same way as a rule.

When paralysis and anæsthesia coexist from disease of the spinal cord or spinal nerves, the prognosis and the treatment are similar for both. Very often the anæsthesia is much less marked than the paralysis, and it recovers more quickly in the favourable cases.

Anæsthesia of the sensory portions of the trigeminus has also been observed. Fagge quotes from Romberg a case which came on after exposure to cold and might therefore be of a similar nature to the cases of facial paralysis produced in the same way. Serious disease in the neighbourhood of the Gasserian ganglion may also produce anæsthesia of the face.

263. **Neuralgia. Referred pains.**—The word neuralgia is applied to many different conditions in which pain is felt in the course or area of distribution of a nerve, and the term might perhaps be defined as pain in the region of a nerve in which no inflammation or other morbid state can be discovered. The pain of neuralgia is also generally an intermittent pain. It is well known that a neuralgic pain in one part may be set up in a reflex way by irritation acting upon some more or less remote part. Fagge has given as an instance the trigeminal neuralgia so often excited by disease of a tooth, and severe supra-orbital pain may be instantly produced in some people by the eating of an ice. Neuralgia of the testis from renal calculus is another familiar instance of reflex neuralgia.

Head has elucidated the whole subject of reflected or referred pain in a masterly series of papers,* and has conclusively shown that the whole surface of the body can be mapped out into areas, each of which corresponds to certain visceral organs. In cases of referred pain we are enabled through Head's researches to form useful opinions as to the probable position of the irritation concerned in any given instance, and this greatly increases the chances of successful treatment.

An important point in true referred pains is the presence of cutaneous tenderness. This has been pointed out by Head and Mackenzie, and is especially insisted on by them as a valuable

* *Brain*, Parts 61, 62, 67. 1893, 1894.

means of distinguishing between referred and other forms of pain.

When we compare sensory with motor nerves we find an analogy between anæsthesia and paralysis, and between neuralgia and muscular spasm. The two latter are especially associated with irritation, direct or reflex, of sensory or motor nerves or nerve centres. And we may also learn from the comparison of motor and sensory phenomena that just as in the case of paralysis the lesion producing it may be in the motor fibres or the ganglion cells, or in the motor tracts of the spinal cord or brain, so too in the case of sensory disturbances, the lesion producing them may occupy any part of the sensory tract, peripheral or central. For example, the neuralgic pains which follow herpes zoster are due to changes in the posterior root ganglion. It is therefore necessary before arriving at any final opinion as to the cause of a neuralgic pain, to explore all those parts so far as is possible.

It is useful to distinguish between pains referred to the area of distribution of a sensory nerve and pains felt along the course of the nerve trunk itself. The former are more particularly associated with the sensory fibres proper, and the latter with the *nervi nervorum* which supply the perineurium of the nerve trunks with sensibility.

In all cases of neuralgic pain it is of especial importance to examine carefully for the possible existence of pressure or deep-seated inflammation of nerve trunks as a cause of the pain. Thus a brachial neuralgia may be due to new growths of the cervical vertebræ, and sciatica to inflammatory processes or new growths in the pelvis.

The electrical treatment of painful affections takes either of two different directions. In the treatment of referred pains the principle of counter-irritation is followed, and by the production of painful cutaneous impressions it is sought to create a diversion, as it were, in the nature of the impulses conducted along the nerve, and so by influencing the centres to remove the neuralgic condition. Counter-irritation is a very popular treatment for neuralgic pains, and electricity affords a counter-irritant of great convenience in application, because it does not damage the skin in the way that blisters or the cautery do.

Duchenne's method of treating neuralgia consisted in severe induction coil applications to the painful area, using a coil with

a long secondary wire and a wire brush electrode on the dry surface of the skin. If the skin were not first dried the current penetrating the tissues to the trunk of the nerve was likely to do harm instead of good.

This method is quite suitable for referred pains, but if used for the treatment of painful neuritis, it is likely to increase the pain rather than to relieve it. It is a common experience to be consulted by patients with sciatica or brachial neuritis, who say that they have "tried electricity, but that it seemed to make the pain worse." On enquiry it usually turns out the "electricity" so unsuccessfully tried has been the current of an induction coil.

For referred pains the static brush discharge, or the brush discharge of a high frequency apparatus may also be employed. The latter may be so pushed as to act as a severe counter-irritant, even blistering of the surface can be produced by it if necessary.

264. **Trigeminal neuralgias.**—The areas supplied by the fifth cranial nerve are often the seat of referred pains. These are excited by disturbances in many parts of the head, neck, and face. The nose, the eye, the ear, the teeth, the tongue, the salivary and other glands, the tonsils, the larynx, and lastly the brain itself, are enumerated by Head as sources of referred pains in the trigeminal or other areas of the head and neck. Neuralgias of the head and neck are also produced by irritations coming from many of the viscera. When it is remembered how large a part of the thoracic and abdominal viscera receive a nerve supply from the vagus or the glosso-pharyngeal nerves, which are of cranial origin, this connection between disturbances of the viscera and referred pains in one or other area of the head and neck becomes intelligible.

The form of trigeminal neuralgia which calls for special notice is that known as tic douloureux. The great suffering produced by this condition often leads patients to undergo severe surgical operations for its relief. This complaint is entirely different in its nature to the "referred pain" group of neuralgias. Almost certainly it is a central affection of the Gasserian ganglion, or of the central nucleus of the fifth nerve.

In the treatment of this form of trigeminal neuralgia no benefit can be obtained from the ordinary procedures of electrical treatment which suffice for the simpler reflex neuralgias of

the face. In general the attempt to treat such cases in this way serves only to determine a paroxysm of pain. A method of treatment by electrical applications, devised by Bergonié, has proved successful in quite a number of cases in the hands of several different observers, and certainly demands attention in this country. It consists in the use of very large currents applied by means of an electrode which is so shaped as to cover the entire side of the face. The polarity preferred for the active electrode is the positive, the current should be pushed to a magnitude of 60 or 80 milliampères. If great care is taken to mould the electrode carefully to fit the surface, and if the currrents are very gradually increased at the commencement, and very gradually reduced at the end of the application they can be borne without discomfort and without damage to the texture of the skin. The duration of each application should be half an hour, and it must be repeated daily until the tendency to paroxysms of pain has disappeared. The skin may still be tender to a touch, but, if no paroxysms are felt, a month's interval should be given, and then the applications are to be repeated as before at longer intervals.

The electrode applied to the face is made of metal cut out roughly in the shape of the capital letter E, the three branches are applied to the forehead, cheek and chin, the eye and the mouth occupying the two gaps between the branches. The patient must recline on a couch during the application. The indifferent electrode is also to be a large one adapted to the upper part of the back, or to the abdominal surface. Bordier recommends aluminium as the most convenient metal for the electrodes.*

265. **Perineuritis.**—The distinction between pain in the area of distribution of a nerve, and pain in the course of a nerve trunk has already been touched upon. In the latter case the disorder is most probably situated in the interstitial tissues or sheaths of the nerve trunk, and the pain is an expression of the implication of the *nervi nervorum* in the morbid process.

Most of the painful affections of nerves may be classified either as referred pains or as perineuritis. Cases belonging to the first group may be treated successfully by induction coil

* See *Archives d'électricité médicale*, 1897, page 377, for a series of cases reported by Bergonié, Bordier, Guilloz and Debedat, and *Ibid.*, 1902, page 135, for a successful case reported by Vernay of Vienna.

applications, which relieve by their action as a counter-irritant, but the method is by no means suitable for painful neuritis or perineuritis, as we have already stated. The treatment of tender nerve trunk cases is an important part of electro-therapeutic practice, but is by no means a simple matter, for in many instances the affections which come under this category, are of an obstinate character. Sciatica and brachial neuritis are two familiar types of painful neuritis for which electrical treatment is frequently applied, and though they are common disorders there is a certain degree of misapprehension as to the principles to be followed in applying treatment.

It a commonly accepted notion that massage is good for these disorders, gymnastic exercises too are often recommended as a means of obtaining relief, and patients will often persevere with these kinds of treatment in spite of an increase of pain as a result of doing so.

The cardinal principles upon which the treatment of painful neuritis should be founded, are rest, warmth and electricity, and the latter must be used as a sedative and for its vaso-motor effect, and not as a stimulant of muscular or nervous activity. The direct current must therefore be used exclusively, so long as there is any pain in the nerve trunks when the affected limb is at rest. When the later stages of the case are reached, and pain is felt only during certain movements, the activity of the congestion or inflammation is less severe, and the sinusoidal current, administered through the medium of the monopolar or dipolar bath, is a very useful mode of treatment.

266. **Brachial neuritis.**—This is a common form of nerve trunk pain, and one which may last a long time. The usual causes are injury or exposure to cold; while gout, alcohol, rheumatism or syphilis, may be predisposing causes.

It is important to exclude pressure from aneurysm or new growth before making a diagnosis of simple neuritis. A common instance of brachial neuritis is the pain in the shoulder formerly called deltoid rheumatism, which is a neuritis of the circumflex nerve.

In other cases the neuritis may involve a greater or lesser part of the brachial plexus and the pain may be severe. Thus in one patient who was under my treatment, a touch in the axilla was sufficient to cause violent shooting pains which were felt down the arm and forearm, and even in the hand.

The important points in the treatment of brachial neuritis are to prescribe rest, warm applications, and with electricity the direct current. Induction coil applications, massage, and exercise are all bad, and tend to make the condition worse. This is especially the case when there is pain even during quiescence of the limb. Both in brachial neuritis and in sciatica this forms an useful means of estimating the severity of the case. When they are acute the pain is felt even when the limb is at rest, and often it is severely felt during the night time. If, on the other hand, the pain is only felt during movement the case may be considered to be less serious, and more vigorous measures may be used in treating it. At that stage the sinusoidal arm-bath may be usefully employed to supplement or to replace the direct current.

Large electrodes and large currents are recommended, the positive pole over the cervical spine, the negative to be moved smoothly over the whole affected area.

267. **Sciatica.**—This term is applied generally to pain felt in the region of the sciatic nerve, and it covers several distinct conditions. Thus the pain may be due to pressure upon the nerve within the pelvis, and it is well to remember that sciatica due to this cause is sometimes noticed in early pregnancy. New growth will also give rise to sciatic pain, and this must be borne in mind, particularly when the pain complained of shows a progressive increase in severity.

Sciatica may be a referred pain, and Head has pointed out that affections of the prostate may cause a referred pain whose distribution resembles that of true sciatica. The same may be said of piles or anal fissure. Pains due to morbid changes at the hip-joint may also be confounded with sciatica.

"Neuralgic" pains in the sciatic nerve may occur, but in most cases the affection giving rise to the pain of sciatica is a perineuritis of the trunk of the sciatic nerve.

The electrical treatment of a case of sciatica must necessarily be based upon a proper diagnosis of its cause. For the referred pains or neuralgias electrical counter-irritation with induction coil currents is a successful treatment, and the effluve of a high frequency apparatus may also be used.

The treatment of sciatic neuritis or perineuritis must be conducted upon different lines. It will be necessary to follow the rules laid down in the preceding paragraph and to use direct

current for its sedative effect and its vasomotor effect. As large currents are needed by reason of the deep position of the nerve it is necessary to use large electrodes, and to give long applications. Fifteen or twenty minutes is a proper duration, and the current may reach 30, 40, or 50 milliampères.

One electrode should be held by the patient against the corresponding iliac fossa, while the other is applied along the course of the nerve on the posterior aspect of the thigh. Authorities differ as to the best direction of the current. Steavenson* recommended a descending direction, with the kathode applied in a labile manner along the back of the thigh, and the anode fixed on the lumbar spine or on the abdomen.

Direct applications of high frequency, by means of pads applied in the same manner, have also been of use in the treatment of sciatica of the neuritic type.

In clinical practice the treatment of sciatica is often very tedious. Patients will often drag on for months with an old standing sciatica which no treatment appears to relieve. The reason for this is not difficult to understand. In the early stages of sciatica there is congestion or inflammation of the nerve trunk, and the pains are not usually so acute as to compel the patient to lie up. Consequently the limb does not receive the rest which is essential to recovery, the congestion is increased by the actions of standing, of walking and of sitting, until eventually adhesions are formed between the nerve and the surrounding tissue, and these irritate the nerve during movement and keep up the pain.

A thickening of the sheath of the nerve may also be caused by the long continued congestion, and this thickening tends to interfere with the nutrition of the nerve. Moreover, it commonly happens that massage is tried in an early stage of the attack, or the patient may try to "walk off" the complaint. The result is that cases of sciatica of long standing are abundant, and are very difficult to relieve by electrical treatment of any kind.

In the early stages of sciatica due to perineuritis the constant current must be used, and the urgent need of rest should be insisted on. This treatment should be uniformly followed so long as the pain in the trunk of the nerve is felt during conditions of repose.

* *Lancet*, January 1884, and July 1886.

When the acuteness of the attack is subsiding, and pain is only felt in movements of the limb a very valuable treatment is that of the electric dipolar bath with sinusoidal current. This gives rapid relief to very many cases, and a test which will determine whether sinusoidal baths are suitable for the case can readily be applied by giving a bath and observing the effect. If the patient finds that the application provokes the sciatic pain, the nerve is still too sensitive to bear this form of application, and the direct current must be continued for a longer period. On the other hand, if the patient feels comfortable in the bath the case is ripe for treatment on those lines.

The condition of a patient whose sciatic pain is due to adhesions is often deplorable. The pain goes on for month after month, in spite of applications of various kinds, and the question of treatment is a very difficult one.

It is quite certain that adhesions may cause sciatic pain, and that the breaking down of an adhesion may be followed by the disappearance of the sciatica.

Thus a patient of mine, who had had sciatica for nearly twelve months, experienced a sudden pain in the back of the thigh. It occurred as the result of a careless movement made while he was dressing himself. So severe was the pain that he went back to bed, but in a few days the pain had subsided and his sciatica had disappeared.

An operation for the exploration of the nerve and the division of any adhesions found will often put an end to a sciatica due to this cause. The operation of nerve stretching was no doubt a method of breaking down adhesions but it was accompanied by considerable risk of injury to the nerve fibres, and is now less often practised. A better operative procedure is the division of any adhesions found, and perhaps the longitudinal splitting of the sheath of the nerve, if that is found to be thickened.

The possibility of breaking down adhesions by massage or manipulation of the limb should be borne in mind before deciding upon a surgical operation. As the employment of massage in early sciatica has already been condemned it will be seen that procedures considered injurious in early cases of sciatica may be of prime value at a later stage of the complaint, and the difficulty will be to decide when any given case is to be treated according to the one method, and when according to the other. In a general way it may be considered that pain occurring only

on movement, and especially if it occurs only with certain special movements, is due to adhesions.

The principles laid down in the two previous paragraphs will serve as a guide in the treatment of neuralgic and of neuritic pains respectively.

268. **Neuralgic pains of herpes zoster.**—The neuralgic pains which are sometimes left after an attack of herpes zoster are due to occurrences in the ganglion of the posterior root or roots involved, and these may be regarded as of the nature of cicatricial changes following the acute inflammatory process in the ganglion which belongs to the period of the attack of zoster. Treatment by direct current applied to the region around the affected nerve roots may be employed. In many cases this form of neuralgic pain tends to remain as a habit after the subsidence of changes in the ganglion, and when that is the condition it can be successfully cleared away by electrical applications.

269. **Acroparæsthesia.**—This name is given to a condition which is very common in out-patient practice.* The patients are generally women between the ages of 40 and 55 years, and they complain of feelings of numbness and tingling in the hands and forearms. The symptoms are especially noticed in the morning on awaking from sleep, and patients often say that they are in the habit of rubbing the hands when they wake in order to bring sensation back. A dull aching or burning feeling is also complained of and some muscular weakness is present. Rarely there may be a little wasting of the intrinsic muscles of the hands. Treatment by arm-baths with sinusoidal or interrupted current gradually removes the trouble, though it may last for several months. Bromides are useful as a drug treatment.

270. **Optic neuritis and atrophy.**—Electrical applications of direct current have been used for optic atrophy and optic neuritis, and several cases have been reported in which improvement of sight has followed. When atrophy comes on without previous optic neuritis, the prospects are considered less favourable. The treatment is by transverse currents through the temples with reversals, and by longitudinal currents through the head, with the anode over the closed eyelids.

The prospects of improvement depend much upon the nature of the disease; when this is of a progressive kind, as in tabetic

* See also an Article by Dr. Edgeworth, *Lancet*, June, 1900.

atrophy, good results can hardly be looked for. Capriati* recommends a trial of the method, and considers that he has obtained improvement with battery currents of two milliampères applied longitudinally. His views have been summarised as follows :—Electrical treatment is indicated in tabetic atrophy of the optic nerve, in cases in which the disease is not running a very rapid course, and before it has reached a very advanced stage. If employed in the early stages it appears to do good, and, with certain limitations, arrests the morbid process, apparently by acting on the nerve fibres still unaffected. Better results may be anticipated from the application of the current antero-posteriorly than transversely, although neither method has yielded results warranting great enthusiasm. In neuritis affecting the nerves of special sense we usually have to deal with a progressive and degenerative state, and on this account treatment cannot give results like those which may be expected to follow simple traumatic lesions of the ordinary mixed nerves.

271. **Auditory nerve deafness.**—The treatment of nerve deafness by electricity sometimes gives good results. The method best suited is with the bifurcated electrode (fig. 112) and the battery current, using the negative pole to the ears. The current should be gradually varied during the whole time of the application by using a rhythmic interruptor, or by turning the current on and off by hand with the current collector (§ 77). It should not exceed ten milliampères. The patient must be watched for signs of faintness, as syncope may even be produced with currents which are too strong. Sittings of six to eight minutes should be used, and to avoid the production of giddiness the application should be made to both ears at once.

An inch is a suitable diameter for the electrode surfaces. If they are less than this some soreness of the skin may be produced at the points of contact from electrolytic action. A small pad of moist absorbent wool placed between the electrode surfaces and the skin provides a better fitting contact than the direct application of the leather covered metal. These precautions are necessary because the electrodes are so small, and the density of current is consequently great.

Under this treatment many patients will have the hearing improved, and I have seen a decided effect follow even the first

* *Riforma medica*, October, 1893. Abstract in Weekly Epitome of *British Medical Journal*.

applications, and the result may be permanently good. The causes of nervous deafness of course are numerous, and the cases should be chosen; only those which from their history and the results of electrical testing appear to be favourable should be undertaken. The best results follow on prolonged courses of daily treatment, and intelligent patients can be taught how to carry out treatment for themselves and should be encouraged to persevere for one or two months.

272. **Deafness in middle ear disease.**—Many cases of deafness are considered to be partly of the nature of nerve-deafness, but they occur in patients who have signs of middle ear changes as well. Tinnitus aurium is often present in these cases, and the treatment of both symptoms by electricity is often attempted. Sometimes the results are good. When the deafness is the most prominent feature of the case the treatment already described in the last section is to be employed: an amelioration of the deafness is not infrequently obtained, and it is not impossible that long continued treatment may have an useful effect in combating the tendency to middle ear sclerosis. Further investigation in this direction is necessary. Probably the results of treatment would be better if larger currents could be used, but the nearness of the brain, and the deep-seated position of the auditory nerve are difficulties. Still it is quite certain from the physiological effects produced that currents can be made to penetrate to the auditory apparatus.

273. **Tinnitus aurium.**—Subjective noises in the ears can sometimes be dispelled at once by the battery current.

Tinnitus complicates nearly all the different forms of ear disease, for instance, it may depend upon the accumulation of wax, or it may be due to some other temporary disorder of the ear, which can easily be cured by proper local treatment, or it may occur in patients whose auditory apparatus is normal, from the action of drugs, from changes in the circulation, or as a part of some general morbid condition.

More commonly, however, some chronic ear mischief exists and the removal of the subjective noises may be a matter of great interest to the patient, even apart from his deafness. When patients are electrically tested it is found that sometimes the tinnitus is associated with greatly increased irritability in the auditory nerve, which is shown by the ready production of an impression of sounds by small currents. As a rule the

kathodal closure produces an increase of sound and anodal closure reduces the intensity of sounds which are present, and this effect is very well marked in these patients. The effect of the anode in diminishing the noises, which it probably effects by an action of electrotonus, has led to the adoption of electrical treatment for this condition of tinnitus aurium. It is carried out as follows:—The direct current is used and a resistance apparatus (§ 79) of twenty or thirty thousand ohms is included in the circuit, so that a gradually increasing resistance can be used as a means of slowly reducing the current at the termination of the application. The binaural electrode is arranged as already described and the patient connected up in the usual way. Current is then turned on gradually. When the galvanometer indicates eight or ten milliampères, each ear is receiving half that current, and this strength is sufficient. During the application the patient should be instructed to pay attention to the noises and to give notice of any change occurring in them. The usual effect of the application of the anode to the ears is to diminish the noises, while that of the kathode is to increase them. If the current be too quickly reduced at the end of the treatment the noises may return as loudly as before, but if it be reduced very slowly and gradually this does not happen. On this account the rheostat is an important part of the apparatus; at the end of the sitting the current is to be reduced by the rheostat first and afterwards by the collector. If it happens that the tinnitus is dispelled by the treatment, at first the relief is quite temporary and the noises will probably return within an hour, but after each sitting the period of quiet is longer, until finally they disappear altogether. If the sittings are repeated daily for the first week much time will be gained, afterwards it will be sufficient to apply the treatment twice or three times a week for a month or more, according to the progress of the case.

Various other electrical applications have been advised for tinnitus aurium. Brigade-Surgeon W. Price, writing in the *British Medical Journal* in 1900, describes a method which he has found efficacious in his own case. He writes:—" The negative cord from a good coil is attached to a large copper electrode, from the positive terminal two cords are brought, each attached to an ordinary hand electrode. Both feet are placed against the negative electrode; each hand grasps one of the positive electrodes. The coil is now set working until the strength of

current is as much as can be endured with comfort. The knuckles of one hand are now applied to the affected ear. The amount of current passing through the ear can be regulated to a nicety as follows:—Slightly open the hand against the ear; the current is at once proportionately decreased. Shut that hand while opening the other, and the current through the ear is at once increased. In my case this treatment is followed by almost instant relief, and the 'cure' is quite as permanent as when the case is left to Nature. When it threatens to return another application relieves."

The brush discharge of the static machine directed into the external auditory meatus has also been recommended.

Dr. Fergusson* has advocated high frequency applications for the treatment of some forms of deafness, and has reported five cases. The "effluve" to the ears, and auto-conduction in the large solenoid were the methods which he employed.

* *British Medical Journal*, 1903, ii., p. 1065.

CHAPTER XIV.

Other Conditions in which Electrical Treatment is Service.

In inflammatory conditions. In joint affections. Myalgia and myasthenia. Disorders of the circulation. The respiratory apparatus. Gastric disorders. Constipation. The urinary apparatus. The generative organs. Diseases of women. Cutaneous affections.

274. **Inflammatory affections.**—Although the general adoption of electricity for the treatment of paralytic conditions has tended to divert attention from many of its other applications, its uses in the relief of congestion and in promoting the absorption of inflammatory products should occupy an important place in therapeutics.

This effect of electrical applications was investigated by Remak* in 1856.

He made use of the continuous current exclusively, and, so far as one can judge, the magnitudes of current employed by him were fairly large. There is no doubt that his views on the subject were correct, and that the direct current may be regarded as having a special power of improving the circulation in a part, and as being of great value in promoting the removal of œdema, and of other chronic conditions due to inflammation. Enlarged lymphatic glands for instance decrease in size under electrical applications. In the *Archiv. d'élect. médicale*, vol. i., will be found an instructive paper on this subject with reports and summaries of twenty-three cases by Dr. Labat-Labourdette. He considers the method of great value in cases of simple chronic adenitis or in tubercular adenitis in its early stages. The treatment is not to be applied when caseation or suppuration have commenced. The negative pole is to be applied to the region of the affected glands.

Moritz Meyer is quoted by Erb as having seen deep cicatrices in muscle soften and disappear, and periostoses from gunshot injuries absorbed with remarkable rapidity. Both effects were

* *Galvanotherapie*, R. Remak, 1856.

procured by the use of the positive pole. Cheron again has seen stiffness of joints and plastic exudation from gunshot wounds removed, chiefly by the application of the kathode. The question of choice of pole may be regarded as of minor importance.

Keloid scars have also frequently been reported to have disappeared under electrical treatment, but it must be borne in mind that they may fade away spontaneously.

Several writers have reported favourably of the treatment of ascites and of hydrocele by electricity. In ascites the induction coil current applied energetically for fifteen or twenty minutes so as to set up vigorous and repeated contractions of the muscular walls of the abdomen, has been followed by increased flow of urine and disappearance of the ascites. The prospects of permanent cure must depend upon the cause of the ascites in each particular case.

It is probable that battery currents might act even better than coil currents for the relief of this condition, by their greater action upon the vascular system of the abdominal organs.

275. **Joint affections. Arthritis.**—As an example of the effect of the battery current in relieving severe congestion caused by injury to a joint the following case, reported by Remak, seems to be worthy of being reproduced in abstract.

"A washer-woman, aged 36, fell from a table and felt her right foot to be twisted outwards; so much pain was produced that she could not walk. During the rest of the day and through the night she applied cold water dressings. The following day she consulted Remak; she was obliged to drive to his house, and ascended the stairs with great pain and difficulty. He found the dorsum of the foot much swelled, livid and very tender; the diagnosis made was laceration of some of the tarsal ligaments, and extravasation of blood. The aspect of the foot was such as to lead to the apprehension that gangrene might result. At the patient's urgent request electrical treatment was applied. Owing to the thickness of the skin of the sole of her foot it was necessary to use a large number of cells in order to produce any sensation or reddening of the skin. By repeatedly changing the place of application of the electrodes he continued the application for twenty-five minutes. During this time the livid coloration disappeared, the œdema and the pain diminished considerably, and the patient could rest her heel upon the

ground better than before. The warmth of the foot, increased by the current, continued until the evening, by which time a decided improvement was established, and she passed a good night without pain. Next day the colour of the foot was normal, and the symptoms were less severe; the treatment was repeated on this and on the next three days. She was then so much better as to walk without lameness, and in a fortnight was practically well." The mode of application is not clearly stated, but it appears probable that the positive pole was applied chiefly to the sole of the foot, but also to the dorsum, while the negative was on some indifferent part higher up the limb or on the trunk. The view taken by Remak in this and in similar cases which he reports, is that the current produces a marked increase in the rate of circulation through the part treated by a general dilatation of its blood-vessels, and as a consequence of the improvement in the circulation the products of effusion are much more rapidly carried off than would otherwise be the case. This view is reasonable, and is perhaps the only one which is capable of explaining the rapidity of the cure.

With chronic joint pains of rheumatic origin the local application of the battery current, by means of large pads, proves equally useful. Excellent results follow in patients in whom the joints continue to be stiff and painful after the subsidence of an attack of rheumatic fever.

Remak quotes a case where there had been rheumatic fever; the patient was ill for seven weeks in his own house and for ten weeks in hospital. When discharged he was thin and pale, his joints were stiff, especially the knee and ankle joints, round which there was thickening. He was then treated by continuous currents applied to the several affected joints, and after six days of treatment was much more free from pain, had more power, and the thickenings had nearly disappeared.

In gouty arthritis electrical treatment will hasten the recovery when the acute paroxysm is over. In the case of a hand or foot the part may be immersed in warm water to form a local bath, as described in detail in § 154, which see.

In those cases of chronic joint affections which I have had the opportunity of treating relief has commonly been afforded, sometimes after a brief course of treatment. Chronic rheumatic joint pains will often yield in a most remarkable manner to electrical applications, even when they have proved most obstinate to

other forms of treatment. The best method of applying electricity is by local applications of the negative pole.

Danion,* in 1887, wrote on the subject of the treatment of joint affections by electricity. In his book he reports many cases in which successful results followed, and his work may be consulted with advantage by those wishing to follow up the subject.

Among recent writings on the subject of the value of electricity in the treatment of stiffened joints, a paper of Professor Leduc (*Arch. d'électricité médicale*, 1894, p. 478) is to be noted, for it gives us the evidence of an exact scientific observer. He describes the case of a young lady who developed phlebitis after typhoid fever. Following upon this there was a stiffening of the left knee joint which was treated unsuccessfully in various ways for more than a year. At the end of that time the joint was ankylosed, immobile, and painful; it felt cold to the touch, and the tissues surrounding the joint were thickened and slightly œdematous. The patient could not walk nor bear with any weight on the limb. Electrical treatment was commenced. A large electrode (negative) was moulded to fit the region of the joint, the positive indifferent electrode being applied to the epigastrium, and a current of twenty milliampères was applied for ten minutes. Afterwards thirty and forty-five milliampères for fifteen minutes were employed. Improvement quickly began and after twenty-two applications extending over two months the joint had become freely movable and the patient could stand and walk.

Other cases of the same kind are referred to and the writer concludes by saying that the useful action of electricity in cases of joints stiffened by past inflammation is incontestable. A point of importance for success is that the treatment must only be applied to joints which are no longer the seat of inflammation. It is necessary to wait until all active mischief in the joint has subsided.

In another paper by Professor Leduc, seven cases are reported which afford valuable evidence of the advantages to be derived from applications of electricity to joints stiffened by old injury or past inflammation. One, a rheumatic case, in a gentleman aged 47, was such that for two years the patient had to be

* "Traitement des affections articulaires par l'électricité." Paris, 1887, p. 238.

dressed and carried from his bed to his couch by attendants. He could not stand up. After thirty applications of the battery current during sixty days he could walk well enough to undertake a journey to Paris, and his improved condition was well maintained.

276. **Rheumatoid arthritis.**—Mention has already been made in § 215 of the treatment of this disease by general electrisation. The sinusoidal bath is a therapeutic agent of very great value in many cases of rheumatoid arthritis. The obscurity which still surrounds the etiology of this disease makes all attempts at its treatment empirical, and although the electric bath is a very useful mode of treatment, yet it still leaves something to be desired. So far as individual cases are concerned it would be easy to relate instances of remarkable improvement following treatment by the electric bath, but from time to time cases are met with which seem to show no improvement at all from this method. Rarely, it may even appear to aggravate the complaint. This has been my experience in two cases, and a possible explanation may be that if the commencement of the electrical treatment should happen to coincide with an acute exacerbation, the treatment may be unable to arrest it, although at a more favourable period, when the attack is over, it may be of service in reducing the damage done.

It is possible that future progress in the electrical treatment of rheumatoid arthritis may lie in the direct application of large currents to the individual joints, and it is not improbable that the introduction of drugs by electrolytic action into the immediate surroundings of a joint may form a part of this method of treatment. Following the lines suggested by Professor Bouchard, who has indicated that a small quantity of a drug njected locally may have as great an effect at that point as a large quantity administered by the mouth, Dr. Roques, and others, have treated rheumatic joints by the electrolytic introduction of ions of salicylic acid into the surrounding tissues,* and have secured encouraging results.

Apart from this introduction of medicaments by electrical means, it is likely that the copious interchange of ions which is produced by the passage of large direct currents through a part may have an important action in modifying nutrition in a joint affected by rheumatoid arthritis (§ 161).

* *Arch. d'élect. médicale*, 1903, p. 689.

277. **Tubercular joints.**—Chanoz and Lévêque* have reported three cases in which the direct current proved valuable in cases of tubercular joint trouble. In one of these Lévêque was himself the patient, and the results of treating his own knee for tubercular hydrarthrosis were perfectly satisfactory to himself. In two other cases the joints treated were notably improved. Lévêque adds from his personal experiences that the negative pole has the more effect in relieving superficial pain, while the positive pole seemed to exercise a greater effect upon the deeper parts. The currents used ranged between 20 and 50 milliampères. The electrodes were of large surface and were placed on either side of the affected joint.

278. **High frequency treatment in joint affections.**—High frequency applications have been found useful in many instances for various chronic joint affections. In some cases the applications have been in the nature of brush discharges or of sparks, and have been used for the sake of their counter-irritant effect. In others the high frequency currents were passed through the affected joint by means of large well moistened pads placed above and below, or over the articulation, and have seemed to be of real utility quite apart from any counter-irritant action. Denoyés† relates a case of gonorrhœal rheumatism of the right wrist joint which improved quickly when treated in this way after direct currents from a battery had been tried for six weeks without any good effect.

279. **Muscular atrophy and weakness.**—So much has already been written in the preceding chapter on the treatment of muscular atrophy in connection with affections of nerves that it will be sufficient to mention in this chapter that the muscular wasting so commonly observed in connection with joint affections responds very well to simple electrical treatment by induction coil currents, and that this should always be given when it can conveniently be arranged.

The "myopathic" muscular atrophies have already been referred to as being essentially unpromising, whatever treatment be tried for them (§ 232).

The use of electrical stimulation as a means of strengthening the muscles of athletes in training has already begun to receive

* "Essai de traitement des arthrites tuberculeuses," *Arch. d'électricité médicale*, 1903, p. 264.

† Denoyés, "Les courants de haute frequence," Paris, 1902.

notice. Both in America and, to a lesser degree, in this country, trainers are said to use induction coil currents for this purpose (see § 176).

280. **Myasthenia gravis.**—Cases of this disease may come under the notice of those interested in electro-therapeutic matters because of the peculiar reaction (the so-called myasthenic reaction) which is met with in the muscles of such patients. The peculiarity consists in a rapid decrease in the amount of response shown by a myasthenic muscle when it is tetanised continuously by the interrupted current. In other words a myasthenic muscle shows the ordinary physiological effect of fatigue with excessive and abnormal rapidity, so far as the tetanising effect of the interrupted current is concerned; but in spite of this it seems to remains just as responsive to the application of a single closing shock from a direct current source after the tetanisation as before. This peculiarity has been interpreted to signify that the seat of disease in myasthenia gravis is not in the muscle fibres, but must be in the nervous elements.*

281. **Myalgia.**—This is the name given to those pains which are felt in over-fatigued muscles; when patients are in a condition of debility, the amount of muscular exertion which sets up these myalgic pains may be so small that the connection between them and their true cause may be entirely overlooked. Hence myalgia is constantly confounded with hysteria, rheumatic, spinal, and other diseases.† The symptoms are pain in the muscles, made worse on movement, and tenderness. The skin over the muscles may also be very tender. The pains are often referred to one of the tendinous insertions of the affected muscles, and the trunk muscles are most commonly affected. Dr. Inman mentions as common seats of myalgic pains (1) the trapezius at its insertion into the occipital bone and into the spine of scapula; (2) the spines of the dorsal and lumbar vertebræ (origins of spinal muscles); (3) the front of the chest (origin of pectoralis major and minor) producing infra-mammary pain; (4) at the margins of the ribs, or at the pubes (insertions of recti abdominis).

Myalgia may exist in persons who are apparently healthy, and it may be difficult to decide what is the particular cause of

* "Myasthenia Gravis," H. Campbell and E. Bramwell, *Brain*, 1900.

† Inman on "Myalgia," Churchill, 1860.

the muscular fatigue which they suffer from; at the same time their pains may be very obstinate and very troublesome, and may resist all treatment until the diagnosis is clearly established, and rest for the affected muscles can be contrived. The movements which specially aggravate the pain must be carefully ascertained in order to decide upon the exact muscle which is at fault. General or local electrical applications may so improve the tone of the muscles as to enable them to perform without fatigue the work they are called upon to do. Local treatment acts usefully too by improving the circulation in the muscles. The battery current up to 20 milliampères may be used, the anode to the painful parts; the sitting may be terminated by a few reversals. This is the method advised by Erb. Induction coil applications to throw the muscles into contraction and exercise them are also useful. The general electrisation by means of the monopolar sinusoidal bath is also a good method of treatment.

282. **Disorders of circulation.**—General electrisation has been recommended in the treatment of some forms of cardiac neuralgia, in dilatation of the heart, and in cardiac dropsy. It is considered unsuitable for cases with marked arterio-sclerotic changes. Larat has advised the use of the sinusoidal current bath and Cluzet mentions that improved compensatory changes, decrease of cardiac pain, reduction of anasarca and better diuresis have been noticed in cardiac cases treated in this way. Caution should be observed at the commencement of a course of baths, as heart patients may show some dyspnœa or embarrassment of the heart as the result of immersion in the warm water. The temperature of the water should not be more than 93° F. at first, and the patient should enter and leave the bath gradually and cautiously.

The effects of electrisation upon the blood-pressure have already been referred to in § 126. The static charge has a decided influence in raising the blood-pressure, and its effect is increased by the brush discharge or sparks applied to the region of the spine. The effluve and spark discharge of high frequency applied in the same way to the spine is said to produce a rise of blood-pressure, whereas treatment by "auto-conduction" (§ 131) or the condenser couch lowers the blood-pressure.

Bonnefoy* has pointed out the important bearing which the

* *Cannes médicale*, 1903, "De l'Insomnie."

blood-pressure characteristics have as a guide in electrical treatment. After mentioning the good effect which statical treatment has upon neurasthenic symptoms, and especially upon the insomnia of neurasthenics, he relates two cases in which static treatment aggravated the insomnia, and points out that in both instances the patients had high blood-pressures. The increase of the already high blood-pressure by the static electricity had the direct effect of making their symptoms worse.

283. **Cardiac failure.**—The aid of electricity is often invoked for the purpose of resuscitation when death appears to be imminent. It may be applied either in the form of brisk general cutaneous stimulation, as in cases of narcotic poisoning, or with the special objects of stimulating respiratory movements, or of acting upon the beat of the heart.

Direct applications to the heart region do not readily affect the movements of that organ. If they do, the result is quite as likely to be harmful as useful. It is better therefore not to attempt it (§ 170).

In order to act upon the respiratory centres the use of the induction coil, preferably with a long secondary wire and the metallic brush electrode, is advised. The region of the body which is stimulated is not of special importance, the applications may be made to any part which is exposed and convenient of access.

A considerable reflex effect is produced by this cutaneous stimulation, and if the dry brush and the long wire coil are used there is much less risk of producing fatigue or exhaustion of the patient, than if a short wire coil be used with moistened electrodes (§ 64). Stimulation of the face, especially of the nose and upper lip, tend to act favourably upon respiration. Duchenne has shown that stimulation of this kind applied to the precordia or to the skin of the back in the lower dorsal region, also influences the respirations. At the former situation inspiration is chiefly promoted, and in the latter expiration.

The phrenic nerves in the neck can be directly stimulated by the induction coil without difficulty, and contraction of the diaphragm will follow. No inconvenience seems to be produced by the proximity of the vagi. The method is as follows :—Two moistened electrodes of small size, about one inch in diameter, must be connected to the coil, one should have a key for making

and breaking the circuit. These are to be applied under the posterior border of the sterno-mastoid muscles, which should be pushed forward, the key must then be closed and opened rhythmically about every two seconds, each closure causes an inspiration, expiration being allowed to take place during the intervals. This use of the induction coil to set up respiratory movements may be advantageously combined with mechanical artificial respiration by Silvester's method. Electrical stimulation of the phrenics in asphyxia, and in chloroform poisoning, has been successfully carried out. For further details Dr. F. W. Hewitt's book* may be referred to. Stimulation of the epigastric region may cause expiratory movements by acting upon the abdominal muscles.

284. **Raynaud's disease—chilblains.**—The electric bath is useful in cases of defective circulation, as in Raynaud's disease, chilblains, and in cases of dead white pallor of the extremities. Both the continuous and the interrupted current have been employed with good effect. One of the first signs of improvement in the numerous cases of infantile paralysis which have been under my care, is that the circulation in the paralysed parts is improved, the limb becomes warmer, and the chilblains disappear. The applications can be very conveniently made by the bath method. Either a general bath or an arm-bath or a foot-bath can be used.

Dr. Barlow in his appendix to the translation of Raynaud's "Essays on Local Asphyxia,"† recommends the constant current monopolar arm-bath, in the following words:—"The use of the constant current as recommended by Raynaud, has been adopted with advantage by several observers in cases of local asphyxia. The method which has been found most satisfactory by the translator, in four separate cases, has been the following:—Immerse the extremity of the limb which is the subject of local asphyxia in a large basin containing salt and water; place one pole of a constant current battery on the upper part of the limb and the other in the basin, thus converting the salt and water into an electrode. Employ as many elements as the patient can comfortably bear, make and break at frequent intervals so as to get repeated moderate contractions of the limb. In a typical paroxysmal case, if the two limbs are similarly

* "Anæsthetics and their Administration,' London, 1893.

† New Sydenham Society, "Selected Monographs.'

affected, it will be found that the limb which is subjected to the above treatment will more rapidly recover than the one which is simply kept warm."

For chilblains the arm-bath or foot-bath with induction coil is the most convenient domestic remedy, and succeeds in all but the most severe cases. I have used this mode of treatment in a number of cases and have repeatedly seen the prompt disappearance of chilblains follow its use. Moreover patients have several times informed me that after the cure of their chilblains by a course of coil baths they have found themselves with more resisting power afterwards, so that a course of baths at the beginning of winter has been sufficient to get them through the whole of the cold weather without any return of the chilblains afterwards. The effect of the treatment therefore is more or less lasting. In the more severe cases of chilblains the constant current bath must be used. Its effects upon the circulation seem to be more intense than those of the coil, and after a constant current bath warmth and redness of the skin is greater than it is after a coil bath.

Patients who know by experience that they are likely to have severe "broken" chilblains should not delay too long before beginning with the treatment, as the current acts very painfully upon any raw ulcerated surfaces. If these already exist they must be covered with a strip of oiled lint during the bath.

285. **The respiratory organs.**—Statical charging has been recommended as a valuable application for strengthening the singing voice. Bordier mentions that M. Moutier, with the collaboration of M. Granier, of the Opera in Paris, had been able to prove conclusively that electrostatic applications had a favourable influence upon laryngeal fatigue (*fatigue vocale*). Their method consisted in charging the patient negatively, and in using a positive or grounded point electrode applied near to the nose and mouth. A brush made of straw (chiendent) seems to have been preferred to the ordinary form with metallic points. With daily applications lasting fifteen or twenty minutes the observers noted an increase in the duration of the respiratory movements, the pitch of the laryngeal sounds was raised, and the sustained production of the higher notes was made more easy. The quality of the voice also acquired a more "mordant" character, and became more agreeable.

286. **Whooping cough.**—Electricity has been used indirectly

in the treatment of this disease by ozonised air. The investigations of Bordier* seem to show that the number of paroxysms of coughing may be notably diminished, and the duration of the illness shortened by administering an inhalation of ozonised air for ten minutes daily.

287. **Pulmonary tuberculosis.**—The successful treatment of this affection by some electrical method has been frequently attempted. The work of Chisholm Williams has been already referred to in § 140. Gandil,† of Nice, has also advocated the use of high frequency treatment.

Labbé and Oudin have advocated the use of inhalations of ozone in the treatment of pulmonary phthisis.

288. **The digestive apparatus. Œsophageal spasm.**—Under the name of "œsophagism" Bordier defines this condition as a neurosis characterised by muscular spasm of the œsophagus, causing difficulty in swallowing. Cases of this class, who have troublesome dysphagia, but in whom the passage of a sound proves that no organic stricture is present are not very common, but are seen from time to time. A patient of mine, a gentleman of middle age, was very much inconvenienced by this form of spasm. He complained that he was prevented from entertaining his friends at dinner because of the difficulty which he experienced in swallowing; even when taking a meal quietly at home with his family he was much embarrassed by the same trouble. Pain was also felt and was referred sometimes to the epigastric region and sometimes to the sternum.

On several different occasions a short course of treatment by positive static charging, with brush discharge to the neck, chest, and epigastrium, has dispelled the tendency to spasm, and has enabled him to eat with facility and comfort, the improvement lasting for several months after the suspension of treatment.

Bordier recommends the treatment of this neurosis by either direct or by induction coil currents, applied externally to the neck and chest, and in more obstinate cases would apply currents directly to the œsophageal walls by means of a metallic bougie. In cases where a simple static treatment is successful these procedures will hardly be required.

289. **Affections of the stomach.**—Electrical treatment may often be applied with advantage in certain affections of the

* Bordier, "Precis d'electrotherapie, Paris, 1902.

† *Arch. d'élect. médicale*, 1900.

gastro-intestinal tract. Dr. George Herschell,* who has given special attention to this subject, states that by the employment of electricity in a proper manner a cure can be obtained in certain forms of dyspepsia associated with neurasthenic states, that hyperæsthesia of the gastric mucous membrane can be diminished, gastralgia and gastric myasthenia relieved or cured, and that constipation depending upon intestinal atony can be remedied.

In dilatation of the stomach the treatment by high frequency has been strongly recommended by Crombie and Bokenham.† Herschell would distinguish true gastric dilatation from gastric myasthenia, and would expect good results from high frequency in the latter condition only.

290. **Constipation.**—Peristalsis can be set up by electrical currents applied through the abdominal walls, and chronic constipation can be permanently relieved by its use. The poles may be placed, one on the lumbar spine and the other on the surface of the abdomen, they should be of large size; the abdominal electrode should be moved over the whole surface of the belly for a period of five or ten minutes. After a few applications the bowels become more regular. Dr. Wahltuch‡ has reported seven cases in which the continuous current produced good results. His method was to use a large sponge for the positive pole, and an ordinary medium-sized one for the negative. The former was applied to the epigastrium, while the latter was slowly moved over the whole abdominal surface, "in the direction of the intestinal canal from the duodenum to the sigmoid flexure," where it was finally fixed, and the current of from five to thirty Leclanché cells allowed to pass steadily without interruption for ten, twenty, or thirty minutes. The operation was repeated every other day for periods of from three to six weeks. The bowels gradually become regular in their action, although all aperients and enemata were stopped, and they remained so after the cessation of the treatment.

Many other writers have reported similar results, and I have

* "A Manual of Intragastric Technique," H. J. Glaisher, London, 1903. "Practical Lessons in the Treatment of Affections of the Gastro-Intestinal Tract by Electrical Methods." "Medical Electrology and Radiology," London, 1904, A. Siegle.

† *Lancet*, Oct. 18, 1902.

‡ *British Medical Journal*, 1883, vol. ii., 623.

myself obtained notably good results in some cases, though not in all.

Another plan which has been proposed for obstinate cases, is to introduce a bougie electrode (fig. 117) into the rectum, the other pole being kept on the abdomen as before; and to avoid the risk of electrolysis and injury to the rectal mucous membrane, a combined douche and electrode has been devised, and in France a number of cases have been treated for obstinate constipation in this way with success. It has even been used for cases described as intestinal obstruction. It is obvious, however, that the nature of the intestinal obstruction should be fairly well made out before undertaking to treat it by electricity.

An interesting article on this subject by Dr. Larat, of Paris, will be found in Bigelow and Massey's "International System of Electro-Therapeutics."*

Dr. George Herschell recommends the use of three-phase

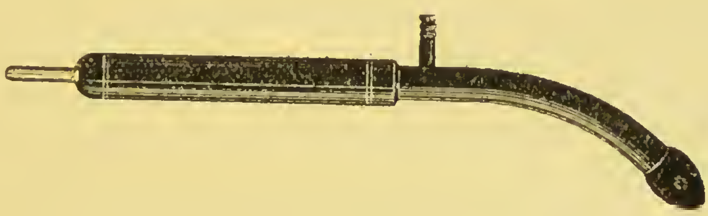


FIG. 117.—Rectal douche electrode.

currents (§ 107) for the treatment of constipation due to atony of the walls of the rectum, and enumerates several arrangements of the three electrodes. In one plan two are placed upon the back, one along each side of the vertebral column, and the third is applied to the epigastrium. In another, a rectal electrode is used, and consists of a bag of membrane surrounding a metallic tube which acts as conductor and also permits of the filling of the membrane bag with water after it has been introduced into the rectum. The second electrode is placed beneath the back, and the third is moved over the abdominal surface. The use of a membranous bag containing fluid in place of a continuous douche presents obvious advantages, as has been pointed out by Dr. Herschell.

291. **Mucous colitis.**—This affection is sometimes very notably benefited by general electrisation, and the electric bath

* Second Edition, Henry Kimpton, London, 1894.

with sinusoidal current may be tried with advantage. Doumer* has found that direct current applied to the abdomen by means of two large electrodes placed in the iliac fossæ has proved valuable in relieving the constipation associated with this condition. Currents from 30 milliampères upwards are used, and reversals are made every minute, the whole time of the application lasting eight or ten minutes.

Laquerrière and Delherm† have confirmed Doumer's observations and consider the results obtained to be brilliant. They report 22 successful results out of 25 cases treated.

292. **Affections of the rectum.**—Electricity has been employed in various morbid conditions of the rectum and anus. In paretic states of the sphincter and in prolapse the application of induction coil currents has been found useful by some writers, and the direct current has been applied with equal success by others.

In pruritus ani the static brush discharge, the effluve of the high frequency apparatus, and the Röntgen rays are all efficacious methods of treatment.

In the treatment of some cases of piles, and of fissure of the anus, high frequency applications are very successful. The method of application is to use a conical electrode of bare metal (§ 143); this is anointed with vaseline and introduced into the anus, and daily applications of two or three minutes duration are given. The patient should lie on the condenser couch (§ 131). In the case of piles the results appear to have been least satisfactory when the state has become chronic, with well marked structural changes in the mucous membrane.

In the case of rectal fissure the same electrode as that employed in piles may also be used, or one of the glass vacuum electrodes figured on page 196. In either case they should be of sufficient diameter to stretch the folds of mucous membrane, in order that the effluve or current may touch the fissure itself.

293. **The urinary organs.**—Incontinence of urine is a symptom for which much can be done by electrical treatment. The cases of this complaint which are met with form several distinct groups. In one, there is want of tone in the sphincter of the bladder, and urine is expelled involuntarily during any muscular effort which involves the action of the abdominal

* *Arch. d'élect. médicale*, 1901, p. 752.

† *Ibid.*, 1902, p. 586.

muscles. In another group of cases occurring in women there is irritability of the bladder and this discharges its contents with pain and spasm at frequent intervals, while in a third well-known form of incontinence the muscular apparatus is normal, but the bladder empties itself spontaneously during sleep.

In women it is extremely common for there to be some inefficiency of the former kind, and in consequence a little urine is apt to be expelled from the bladder during muscular effort such as lifting a weight or during coughing or sneezing. If the weakness of the sphincter be rather more pronounced the incontinence becomes troublesome and annoying, and advice may be sought. The weakness of the sphincter may also be due to some dilatation or, injury of the urethra, for example, during parturition or after a digital examination of the bladder. The tone and power of the female urethra can be strengthened by electrical applications, and the patient's comfort may in this way be greatly increased. I have notes of a patient who suffered from incontinence of this kind, for which she was obliged in the daytime to wear a urinal apparatus, and she was always wet and uncomfortable. A course of electrical treatment completely cured her. In another case, equally successful, the incontinence was the result of an operation upon the urethra for the relief of some painful condition, possibly a caruncle. Since the operation the patient had been unable to hold her water, which escaped during any muscular exertion, so that her condition was most disagreeable to herself. After four or five weeks treatment she was quite well, and able to lift and carry her baby, a strong child a year and a half old, without any leakage from the bladder. Other cases of weak sphincter in which electrical applications have given great relief are those in which the trouble has come on as the result of a long railway journey without any opportunity of passing urine.

Even when the incontinence is part of a paraplegic condition, treatment applied to the bladder may be of service. I have notes of two women who received injuries to the spine through jumping out of windows. They were referred to me for electrical treatment for their incontinence, and in both the power of the bladder seemed to be improved by treatment. At the same time they were and had been improving generally before coming under my care, and therefore the results of the electrical treatment they received are not so conclusive. Bladder weakness

in tabes sometimes undergoes decided, if temporary, improvement from electrical applications to the lower spine and perineum.

The condition of irritability of bladder which produces frequent calls to urinate is one that is commonly confounded with nocturnal incontinence.

There is a class of patient with so-called nocturnal incontinence in whom careful questioning will reveal the fact that there is not only a tendency to wet the bed at night, but also a weakness by day. These cases occur almost exclusively in females. When up and about they are unable to retain their urine with comfort for more than half-an-hour or an hour. If after the lapse of that time they have no opportunity of emptying the bladder voluntarily, pain and spasm come on and the urine is expelled. At night, too, they are obliged either to get up frequently, or else to wet the bed. In hospital out-patient practice patients of this type are usually in a wet condition locally, and their clothing smells of urine, whereas true cases of nocturnal incontinence are not so.

No electrical treatment seems to have the slightest good effect upon the cases just described; and it is therefore very important before giving a prognosis to distinguish them from cases of true nocturnal incontinence, in which electrical treatment answers admirably.

294. **Nocturnal incontinence.**—This affection has a totally different pathology to that of the kind of incontinence already discussed. In nocturnal incontinence the patients are able to retain their urine in a perfectly natural manner so long as they are awake, but when asleep the bladder has a tendency to empty itself without awaking them. The condition is due to a persistence of the infantile mechanism of micturition, and the bladder acts during sleep in an automatic way, the controlling centre in the brain not being strong enough to maintain its action during the condition of sleep. The education of a child includes the education of inhibitory centres which bring the reflex mechanisms of micturition under the influence of the will, so that the action of the bladder in adult life is continually controlled. If the control be imperfect the bladder may empty itself whenever the higher centres are in abeyance, as during sleep. If sleep passes into coma the controlling centre falls into abeyance in any case. A person suffering from nocturnal incon-

tinence may pass water unconsciously in the daytime when asleep in a chair. As a rule sleep is very sound in patients who are the subjects of enuresis nocturna.

Electricity is of use in enuresis nocturna because it is able to stimulate the centres, both cerebral and spinal, by producing painful local impressions which tend in time to bring the inhibitory cerebral mechanism into more close relation with the reflex centres in the lumbar cord.

It is important to try to combat the tendency to very deep sleep which exists in many of these patients. This may be attempted in various ways; for example, the number of the bedclothes should be reduced so that the patients are a little chilly at night; and a clock which strikes the hours is also an useful thing to have in the bedroom, especially if the patient can be taught to awake when the clock strikes twelve, or any other hour which may be specified. They must be taught to practise retaining the urine as long as possible by day, so as to accustom the bladder to become more tolerant of its contents and to augment the influence of the inhibitory centres by the exercise of their functions.

In children with enuresis nocturna it is important to search for any reflex irritation and to remove it when possible. Thus worms, oxaluria, a narrow meatus, or phimosis, if present, must be dealt with before resorting to electrical treatment.

The results of treating nocturnal incontinence by electrical applications are very good. Most of the cases can be cured by attention to the points just enumerated.

The best mode of application for cases of incontinence with weakness of the sphincter in women and girls is to introduce a bare metal sound into the urethra as one electrode, and to place the indifferent electrode upon the lower dorsal region of the back. The sound must not enter the bladder for more than a very short distance, otherwise but little current will pass to the walls of the urethra.

For male patients applications to the perineum will usually answer almost as well as the passage of a sound, and the latter may, therefore, be reserved for the more troublesome cases; the use of a perineal electrode makes the operative procedure more simple and less formidable to the patient. Fig. 118 shows an electrode of suitable shape. It consists of an acorn-shaped piece of metal fitted with a handle, and it is so contrived that a

chamois leather cover can be adapted to it in a moment for each application. A ring of vulcanite pushed on over the piece of leather serves to hold the latter in place.

The currents used must be decidedly painful in order to produce a suitable impression upon the nerve centres. It is useless to undertake the electrical treatment of incontinence without direct applications to the perineal region, and consequently it is very important not to allow incontinence of urine in children to be left untreated in the hope that they may outgrow it, because in girls after puberty the local applications may be a source of embarrassment. Where it is desired to avoid all manipulations of these parts the treatment may be carried out by applications in an electric bath, using a small metal electrode pressed up between the thighs, outside the bathing dress, in place of the ordinary foot plate. The current then passes as desired into the perineal area.

FIG. 118.—Electrode for enuresis.

In the treatment of incontinence of urine the induction coil applied strongly for eight minutes, and followed by a battery current of five to ten milliampères with reversals every five seconds for three or four minutes, seem to give the best results. The constant current without reversals should not be used for fear of injuring the skin and mucous membrane through electrolytic action.

295. **Sexual disorders.**—Various morbid conditions of the male sexual organs have been treated by electricity.

For impotence and sexual debility Erb has advised that a small button-shaped electrode connected with the positive pole be held to the perineum, and another larger electrode (negative) be moved slowly up and down the lower dorsal and lumbar spine. The current may be of from five to ten milliampères, according to the tolerance of the patient, and the time occupied may be ten minutes. Applications daily for a week, then every

other day. In this way the symptoms may be dispelled. Local treatment by means of the wire brush has also been proposed for sexual debility. Electricity is in no way a sovereign remedy for this class of patient, and unless something can be done by enjoining abstinence the restoration of lost sexual powers is generally a vain hope, except where the troubles are mental rather than physical. Even then medical treatment cannot do very much.

In varicocele the pain is said to be relieved by applications of direct current if the scrotum is immersed in a small bowl of warm water connected to the positive pole, the negative pole is applied to the inguinal regions or over the sacrum.

296. **Orchitis.**—Scharff (*Centralbl. f. Krankh. d. Harn und Sex. Organe*, 1, 1894) claims to have employed electricity suceessfully in the treatment of epididymitis. He does not wait until the affection has become chronic, but immediately and during the acute stage applies the anode to the lower part of the scrotum. The patient being in the dorsal position, a large electrode, with a maximum current of half a milliampère is employed, the duration of the application being three minutes on the first occasion; this is afterwards increased to five and ten minutes, the increase being very gradual. The weak constant current thus employed should be carefully gauged with a sufficiently sensitive galvanometer, and the current closed insensibly with the aid of a rheostat. No unpleasant sensation should be thus produced, but the patient will subsequently on palpation be able to observe a considerable diminution or total disappearance of the tenderness which had previously existed. While in the same position a suitable suspender is applied, and the patient then allowed to walk about. Towards the seventh day the current can be increased to three milliampères, the same electrode, however, being still used for a few days, when it can be somewhat reduced in size. The kathode is placed above the groin and on the abdominal wall. By this treatment, rest in bed can usually be dispensed with, the other advantages over the older methods being rapid and marked relief of the pain from the first, and greater rapidity in the disappearance of the swelling. Onimus also speaks very favourably of the good effect of electrical treatment in orchitis, and Dr. Picot, of Tours, has reported good results in forty cases; both used currents of about five milliampères.

Dr. Duboc,* of Rouen, has reported two cases of chronic orchitis and epididymitis following gonorrhœa treated successfully by electricity, one had lasted for eighteen months in spite of much medication, the other for nine months. In both cases the swellings disappeared rapidly and completely after about six applications. Two pads were used, one in front of the testicle and one behind; both were moistened with a twenty per cent. solution of iodide of potassium, a battery current of twenty milliampères was used for ten minutes.

297. **Diseases of women.**—Electrical methods are largely made use of in gynæcological practice, not only for their direct effects, but also for electrolysis, and the galvano-cautery. Much attention has been directed to the subject of the electrical treatment of fibromyoma, and an immense amount of literature has been produced since the introduction of Dr. Apostoli's method of treating that complaint by electrolysis of the uterine mucous membrane.

In pruritus of the vulva, in vaginitis and in vaginismus various electrical procedures may be adopted with success. In the former the brush discharge of the static machine or high frequency apparatus gives relief. The best way of applying the latter is by means of a glass (condenser) electrode.

The use of electricity in diseases of women is so much a matter for the gynæcologist himself that a few brief notices of the different conditions in which electricity can be simply applied will suffice in the present work. Those wishing to study the subject more fully should consult the works of Apostoli, and of his followers. In the "International System of Electro-Therapeutics" of Bigelow and Massey,† a considerable amount of space, nearly 250 pages, is devoted to this section of electro-therapeutic work, and may be referred to with advantage.

298. **The mammary glands.**—Electrical stimulation applied to the mammary glands has been found useful for promoting the secretion of milk in nursing women.

Two patients who were suckling their infants were treated in this way in the Electrical Department at St. Bartholomew's Hospital, for failure in their milk-producing powers. In one case a decided improvement followed. In the other the results were doubtful. It is not often that the advice of medical

* *Arch. d'électricité médicale*, 1894.

† London, Henry Kimpton, Second Edition.

men is sought for producing an increase of the mammary secretion.

Successful cases are quoted by Drs. Beard and Rockwell, and by several recent French writers.

Electricity has also been recommended as a means of increasing the size of the breasts in cases where their development is defective.

299. **Amenorrhœa.**—Electricity has been employed in the treatment of this condition for a long time. Dr. Golding Bird* had a very high opinion of the value of shocks from the Leyden jar for curing this symptom, and writes at some length upon it in his little book. His method was to transmit through the pelvis twelve shocks in succession from a small Leyden jar, the discharge being directed from the sacrum to the pubes. The induction coil current applied to the uterus has also been found efficacious by Panecki and others in patients with amenorrhœa from sluggishness of the uterine functions apart from chlorosis. The electric bath, by its effect upon nutrition, acts as an indirect emmenagogue in chlorosis. When this condition is present general treatment is usually sufficient, and local applications are not called for, and indeed are undesirable. In healthy women in whom menstruation is regularly performed, electricity may certainly hasten the appearance of the flow, especially when it is applied to the abdomen or pelvic region. The electric bath may have the same effect.

It is best to suspend general electrical treatment in women for a few days before the menstrual periods, otherwise the flow may be rendered excessive, and in pregnancy it is better not to employ electricity at all for abdominal or bladder troubles.

300. **Dysmenorrhœa.**—The effect on painful menstruation of the statical breeze has been referred to in § 126. It is a mode of treatment which is easy and gives good results in many cases. The positive charge with the negative breeze to the loins and spine is not a disagreeable mode of treatment. It should be given daily for a week before the date of the appearance of the menstrual flow.

301. **Ovarian neuralgia.**—The abdominal pains felt by women and referred to a tender ovary may be treated by electricity. By some writers these pains are regarded as an

* Golding Bird, "Electricity and Magnetism," 1849, Lecture V., and Appendix B.

expression of a general condition rather than as a sign of local disease, and on this ground the treatment advised is that of general electrisation. Local treatment by direct current may also be employed successfully if large currents and long applications are used. Currents of 40 or 50 milliampères applied by means of large electrodes, placed one on the front of the abdomen and one at the corresponding part of the back are recommended.

302. **The vomiting of pregnancy.**—Drs. Gautier and Larat* have described a series of cases, eleven in number, in which the battery current, stabile, arrested obstinate vomiting of this kind. The positive pole should be applied above the clavicle between the attachments of the sterno-mastoid muscle, while the negative pole is placed at the epigastrium; the current should be of eight to ten milliampères turned on and off very gradually, and continued for fifteen minutes. It may be applied several times daily in severe cases. In from 24 to 48 hours from the first application the vomiting was either greatly alleviated or had ceased entirely.

303. **In parturition.**—In a paper read by Dr. Kilner before the Obstetrical Society,† the use of the induction coil current is advocated during parturition as a means of provoking or of strengthening uterine contractions. Sometimes the resulting contractions were very severe and prolonged, indicating possible risk to the child. The applications seemed to diminish the pains felt during the labour, and after the birth of the child ensured a firm uterine contraction, and much diminished the risk of post-partum hæmorrhage. Some medical men speak very highly of its value in childbirth, and make a practice of carrying a small induction coil in their obstetric bag. It has also been of service in flooding after miscarriage.

It follows that caution is necessary before applying electrical treatment to the abdomen or pelvic organs of a pregnant woman. An early writer speaks of having produced a miscarriage as the result of Leyden jar shocks applied in this way.

304. **Cutaneous affections.**—In § 141 the treatment of various forms of skin diseases by high frequency applications was referred to. Other forms of electrical application may also

* "Traitement par l'électricité des Vomissements Nerveux, et en particulière des Vomissements incoercibles de la Grossesse," Paris, 1895.

† *Brit. Med. Jour.*, April, 1884.

be used. I have seen prompt and permanent healing follow treatment of a varicose ulcer of long standing by the interrupted current. Patients who are taking a course of electric baths usually lose any acne of the skin of the back from which they may have been suffering at the commencement, and the warmth and redness which is produced by electrical treatment of a part is another sign of this direct effect upon the cutaneous circulation. It has long been known that chilblains respond favourably to electrical treatment. These facts all show that the nutrition of the skin can be markedly influenced by electrical applications, and many things point to the probability that electricity will some day occupy an important place in the treatment of skin diseases.

The static breeze, the brush discharge from the Tesla coil, and the Röntgen rays, all show marked effects upon the skin which can often be turned to good account in treatment.

Dr. Marquant* has reported a series of twenty-three cases of eczema and eczematous ulceration treated by the electrostatic brush discharge with very good results. His method had previously been tried by Prof. Doumer, who has also published a communication in the same journal.† The patients were placed on an insulating seat connected to the negative pole of the machine, and the positive pole was connected to a pointed electrode and held close to the affected part. In his concluding remarks, he says that the beneficial effect was superior to that obtained by any other kind of treatment. It was more quickly produced in those patients whose general health was good, than in those who were constitutionally unsound. The local pain, and the congestion and discolouration round the ulcers quickly disappeared, and healthy cicatrisation commenced rapidly (see also § 127 for a reference to a case of lupus cured by static applications).

Oudin‡ has reported a number of cases treated successfully by high frequency discharges, and his observations have been fully confirmed by many other writers.

Denoyés enumerates the following skin affections as suitable for treatment by high frequency discharges:—Pruritus, psoriasis,

* *Arch. d'électricité médicale*, 1893, pp. 329, 385.

† *Idem*, p. 141.

‡ "De l'action des courants de haute fréquence sur quelques dermatoses,' *Soc. de dermatologie*, August, 1894.

eczema, alopecia areata, lupus vulgaris and lupus erythematosus, acne, and impetigo. In all the technique is similar and consists in the use of the effluve of the resonator given without sparking, from a metallic brush electrode (§ 135), or of the finer effluve of the "glass condenser" electrodes, which may either be exhausted to a conducting vacuum or filled with water or salt solutions.

When the condition is chronic, indolent, and dry, it may be useful to apply a few fine sparks to the surface by means of a wire brush. Two or three applications weekly, and a duration of time not exceeding ten minutes are sufficient.

It is also thought that general high frequency treatment by the condenser couch is an useful adjunct to the local treatment, and cases have been several times recorded where general treatment and local applications to one patch of lupus have been followed by a cure of patches of lupus remote from the one locally treated.

305. **Lupus.**—In the case of lupus high frequency applications have a very beneficial action. Chisholm Williams, Hall Edwards, and others, have written on this particular subject. In the Sub-section of Electro-therapeutics at the Swansea Meeting of the British Medical Association,* the former read a paper from which the following extract is taken :—"That the treatment of lupus by electrical currents of high frequency and high potential is a most excellent method will only be doubted by those whose experience of this form of electricity is of a limited character. As early as 1897 Dr. Brocq reported 62 cases 16 of which were failures or abandoned the treatment, whilst the rest were cured. Lately Dr. Bordier has reported a series of 73 cases with a like percentage of cures.

"The treatment may be applied in three ways :—First, by the ordinary brush effluve, this, containing a vast quantity of ultraviolet rays is, or should be, absolutely painless. Secondly, by means of a highly exhausted vacuum electrode attached to the top of the resonator. When this is in actual contact with the skin it is warm, but not painful, and may be regulated by withdrawing it from the skin as desired. These electrodes should, with the fluorescent screen, give evidence of the presence of X rays. Thirdly, by means of general electrisation, preferably by auto-condensation. A combination of this with one of the former methods will prove of the utmost benefit."

* *Brit. Med. Jour.*, Oct. 24, 1903, p. 1061.

Mr. Hall Edwards, speaking at the same meeting, said that he had frequently noticed that in treating one side of the face for lupus, the X rays had brought about a great change for the better in patches of lupus on the opposite side.

The use of X rays as a therapeutic agent has also been successful in many forms of chronic skin affection. Chronic eczema and psoriasis of old standing will both clear up magically when treated a few times by X rays. Rodent ulcer is also favourably influenced by X ray applications, and many cases of this disease have been completely cured by X ray treatment.

306. **In ophthalmic surgery.**—Alleman* in a valuable paper on applications of electricity to ophthalmology, gives an account of the treatment of corneal opacities by the continuous current. He says:—"That from the observation of a number of cases, extending over a considerable time, he is convinced that the use of electricity promises the only treatment of avail in corneal opacities of long standing." The kathode is applied to the cocainised cornea, and has the form of a silver rod, seven millimetres in diameter, the flat end being used; from one-half to four milliampères for one or two minutes are used. He has satisfied himself by strict tests that the results are really good. More care is needed with recent scars than with older ones.

More recently several experimenters in this country have confirmed these observations and have reported their experiences in the *British Medical Journal*. Synechiæ have also been frequently observed to fade and disappear under applications of the battery current through the closed eyelids. Those who are interested in the subject will find a useful paper by Dr. Pansier of Avignon in the *Arch. d'électricité médicale*, 1894, with notes of twenty-four cases. See also a paper in the *Royal London Ophthalmic Hospital Reports*, by Marcus Gunn, on "The Continuous Electrical Current as a Therapeutic Agent in Atrophy of the Optic Nerve and in Retinitis Pigmentosa."

307. **Electricity as a test of death.**—The electrical reactions of muscle afford a complete test of death, as the contractility of the muscles only persists for a short time after death, and then disappears gradually.

If the muscles of a person supposed to be dead cannot be caused to contract when stimulated by the induction coil

* Bigelow and Massey, "An International System of Electro-Therapeutics," Kimpton, London.

current, life may be considered extinct; on the other hand, if they retain the power of responding to this test, death, if it has occurred, must have been so recent that the inevitable changes have not yet had time to affect the muscles of the body. Certainly no person should be buried if his muscles are still normally contractile. The morbid fears of the public on the subject of the burial of persons not really dead could be completely allayed if this test were always applied before the certificate of death were signed.

Onimus and Legros* have shown that there is a stage in the dying of a muscle at which it gives the reaction of degeneration (§ 188), that is to say, the irritability to the induction coil disappears first, while the response to direct battery current stimulation continues, giving rise to a sluggish contraction. This change sets in about four hours after death, and they relate a case in which the reaction enabled them to specify correctly the time at which death had occurred.

Marie and Cluzet,† who have recently repeated these experiments, have found that the muscular excitability disappears more or less quickly according to the nature of the disease which has caused death, and there may be differences in different individuals, but the reactions may begin to change after thirty minutes have elapsed since the time of death, and that a complete reaction of degeneration makes its appearance in one hour.

* "Traité d'électricité médicale," Paris, 1888.

† *Arch. d'élect. médicale*, 1899, p. 543, 1900, p. 285.

CHAPTER XV.

Electrolysis in Surgery.

The removal of hairs, moles and warts. Nævus. Port wine mark. Aneurysm. Stricture of the urethra, of the œsophagus, of the rectum, of the Eustachian tube. Stenosis of the cervix uteri. Electrolysis in fibro-myoma. Extra-uterine fœtation. Cancer.

308. **Uses in surgery.**—Electrolysis is used in surgery as a means for producing destruction of tissue in a simple and minutely localised manner. This is effected indirectly by the action of the chemical bodies liberated at the poles during the passage of the current. As these bodies are different at the two poles, so the actions which take place at the poles differ from one another to a certain extent. The advantages of being able to localise the effects so precisely is well seen in the operation for the removal of hairs, for here the destructive effects are confined to such a minute area in the immediate neighbourhood of the hair follicle that no perceptible scar is produced, although the hair follicle is eradicated. Electrolysis has been used for the following purposes:—(1) The removal of superfluous hair, of moles, and of warts. (2) Destruction of nævi. (3) Coagulation of blood in aneurysms. (4) Destruction of strictures in the urethra, lachrymal canals, œsophagus, rectum, and Eustachian tube. (5) Destruction of cancerous growths, and (6) for the relief of symptoms in fibro-myoma of the uterus. This last is brought about as a secondary process which has been found to follow electrolytic destruction of the uterine mucous membrane.

309. **The removal of hairs.**—If a fine needle connected to the negative pole of a battery of three or four cells be introduced into a hair follicle, electrolysis takes place round the needle when the circuit is closed, and the hair follicle is destroyed by the alkali produced; the hair can then be removed easily and does not grow again.

The method of operating is as follows:—The patient should recline in a good light. Having placed the indifferent electrode (anode) in contact with a convenient part of the patient's body,

the kathode is attached to a fine platinum wire set in a handle, the current collector is turned on to take up four cells into circuit, the operator then introduces the needle as closely as possible to the root of the hair, holding it in the proper direction for it to enter the follicle; the needle passes down readily to the required distance, one-eighth or one-tenth of an inch, a current of about three milliampères passes, slight effervescence is seen at the orifice of the follicle, and at the end of five seconds or so the needle is withdrawn. As a rule the hair can then easily be lifted out by a forceps; if it still remains firm, the needle may be introduced a second time until it is loosened, though this is not a very good thing to do; it is rather better to leave the hair until another day; the current should be just strong enough to produce slight frothing. The best way to learn how to perform the manœuvre is by a few preliminary experiments on oneself. There is a certain amount of pain, but it is within the limit that can be borne without flinching, and an anæsthetic is not necessary. Cocaine cannot be usefully applied.

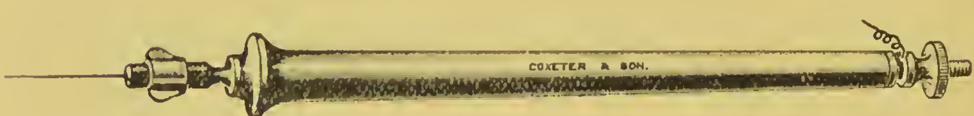


FIG. 119.—Needle electrode for epilation.

It is best to use for the needle a very fine platinum wire, blunt pointed, because such a needle is less likely to penetrate too easily and so to pass away from the hair follicle. It can be sterilised before use by heating to redness, and is better than a steel needle. The latter will leave indelible black marks in the skin if by accident it be connected to the positive pole. The current must be closed before the needle is inserted into the follicle. A key in the handle is therefore unnecessary and troublesome.

A good deal of practice is required to perform this little operation skilfully, for it really amounts to a catheterisation of the hair follicles. No force must be used in removing a hair, if force is used the hair will come out before the follicle is destroyed, leaving its root behind, and a new hair will grow up from it. When many hairs are to be removed they should be done at successive sittings. Patients as a rule become restless from the pain of the operation after a time, and as soon as signs

of this begin to appear, it is best to suspend the treatment. It is possible, however, with a good patient, to remove thirty or forty hairs at a sitting. A tiny eschar with a small zone of redness is left round the follicle. Several hairs in close proximity should not be attacked at one time, for fear lest the nutrition of the skin should be so much interfered with as to lead to a small ulcer and consequent scar, but the hairs should be removed sporadically, until at the final sittings the last remaining ones can be gleaned off and the place left smooth and bare. If the patch of hairs is small the sittings must be less frequent, once a week being quite often enough. When there is plenty of room to attack a fresh part each time the sittings may be repeated more often, care being always taken not to injure the skin at any one point too much.

It is as well to caution patients that there will be a certain percentage of returning hairs, but that these can be dealt with a second time if any should so return.

It is very easy to overdo the treatment and leave scars. It is not wise to attempt the total removal of a fine downy growth of the upper lip of young women.

310. **Trichiasis.**—The removal of eyelashes for trichiasis is satisfactorily accomplished by electrolysis, but it is difficult to carry out owing to the sensitiveness of the part, and the fineness of many of the most troublesome hairs. The results of the treatment of this complaint are very satisfactory. Usually at the commencement of the treatment the corneæ are hazy, in consequence of the continued irritation by the turned in eyelashes. If the removal of the eyelashes be persevered with until every one has been removed, the corneæ will recover their transparency and the patient will continue free from any recurrence of trouble from the ingrowth of the eyelashes.

311. **Moles.**—The best treatment for small hairy moles is epilation; when the hairs have been removed very little will be seen of the mole, for the prominence on which the hairs grow will disappear; a good deal of the pigmentation of the skin between the hairs will also disappear when they have been taken out, but if there be much pigmentation the best treatment is by transfixing the mole in several directions, using the negative needle and five or six cells. The cocaine guaiacol mixture (§ 162) can be very well used to render the part insensitive.

312. **Nævus.**—Electrolysis is a very convenient way of destroying nævi, and for certain cases it is superior to all the other methods, but, to secure first-rate results, a certain amount of practice is necessary, and several repetitions of the operation may be required if the nævus is an extensive one. The chief art in treating a nævus lies in the careful regulation of the current used and in knowing when to stop. It is easy to electrolyse a nævus in such a way as to destroy it and cause it to slough away completely, but this leaves a large scar and is not the best way of attaining one's object. The object to be aimed at in the electrolysis of nævi is to carry the destructive action just so far as to coagulate the blood and break up the blood-vessels without producing a general necrosis and sloughing of the whole. When the nævus is entirely subcutaneous, it is most important to save the skin, for then the nævus is destroyed without any scar except at the minute points where the needles were introduced. When the nævoid tissue is quite superficial and very florid, and involves the actual thickness of the skin, it is difficult or impossible to destroy it without some scarring.

The usual plan of treatment is as follows:—Needles attached to one or both poles of a battery are introduced into the nævus; the current is then very gradually raised from zero up to 20, 30 or 40 milliampères, a galvanometer being included in the circuit.

If both poles are used care must be taken that needles of opposite poles do not touch one another, for if they remain in contact the current simply runs to waste through the metallic circuit so produced, and the nævus tissue is unaffected; if they come into momentary contacts, the patient receives a shock each time they touch and separate. Soon after the commencement of the operation the tissues round the needles begin to change colour; round the positive needles there is hardening and pallor, and round the negative needles frothing is produced with the evolution of hydrogen gas. The positive needles become firmly adherent to the tissues in which they are embedded, and force is required to withdraw them; on this account bleeding is more likely to occur with the positive than with the negative needles. The negative needles become very loose and are apt to slip out, but they must not be allowed to do so, for the current must not be suddenly interrupted for reasons

already mentioned. If the tissues round the needles become livid or blackened sloughing of the part will follow. This change shows itself first at the negative pole. The position of the needles must be changed before this, by taking them out and reinserting them one at a time in other parts of the nævus, until the whole of it has been treated.

The nævus becomes swollen and harder during the process of electrolysis, and the skin round it becomes reddened. About five minutes is a suitable length of time to continue the electrolysis, but this should be varied with the size of the nævus. If the nævus is very extensive it must be dealt with in detail, part being attacked at each sitting until the whole has been destroyed.

The needles are to be withdrawn after the current has been lowered and must not be plucked out while the current is still running strongly. The negative needles are easily withdrawn, but the positive may be adherent and should be twisted out gently. A little bleeding may follow from one or two of the punctures, but it is rarely of any importance. The after-treatment is simple. Collodion containing iodoform, one drachm to the ounce, is to be painted over the nævus ; this can be left for four or five days, it should then be removed, and the place treated with boracic ointment. If any suppuration or local sloughing should develop, a poultice at night, with some zinc lotion by day, will be a suitable treatment. Many of the smaller nævi dry up and need no second application. It is impossible to avoid some destruction of the skin and scarring when the nævus is cutaneous, but the scars produced are much smaller than might be expected, and when seen a year or two afterwards they show remarkably little. Sometimes only one set of needles, usually the negative, is introduced into the nævus, the circuit being completed through the patient's body by using a large pad for an indifferent electrode. In this case the resistance is higher, and a larger number of cells is required. There is a greater risk of shock or faintness, especially with nævi of the head and face, but with care the operation can be carried out successfully. This unipolar method is most suitable in cases where great nicety is needed, as, for example, in small nævi about the eyelids or nose.

Care must be taken that the pad electrode and its conducting wire are well covered and that no bare metal touches the skin

anywhere, any oversight in this matter may lead to electrolysis where it is not wanted, namely, at the seat of the indifferent electrode.

The rate of destruction depends upon the density (§ 160) of current in the part; if needles of both poles are introduced irregularly, it is very likely that the current may be concentrated

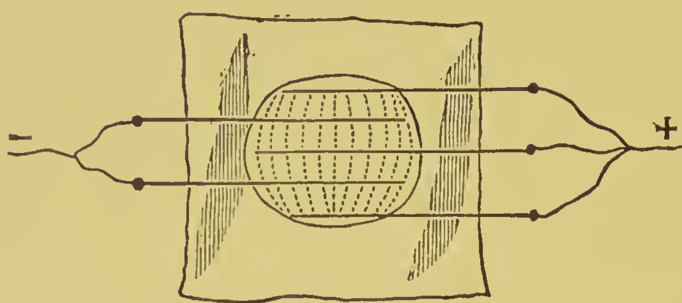


FIG. 120.—Electrolysis of nævus. Proper position of needles.

round the points where they are nearest together, and be very feeble in the more remote parts. The diagrams (figs. 120 and 121) represent the conditions under two different arrangements of needles, in the first the needles are placed in such a way as to be equidistant, and the density of current is therefore uniformly diffused. In the second, they are all very near

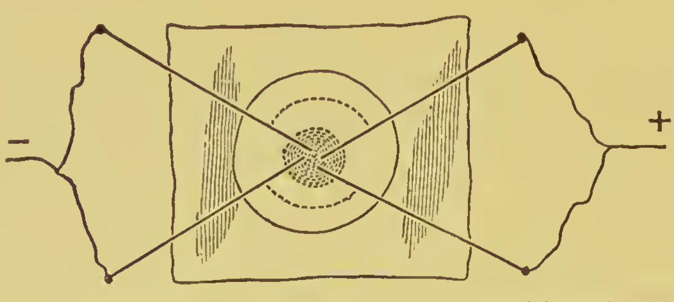


FIG. 121.—Electrolysis of nævus. Improper position of needles.

together at the points and there the current is of far greater density than at the periphery of the nævus, the effect of such an arrangement would be to produce a slough at the centre, while the periphery would not be destroyed at all. In order to simplify the introduction of the needles in a proper manner, the writer* has devised an instrument (fig. 122) consisting of

* Dr. Lewis Jones, *Brit. Med. Journal*, Feb. 20, 1892. "An improved instrument for the electrolysis of nævi."

a handle to carry the needles; two, three, four or five can be screwed into it, and they are so arranged as to be alternately positive and negative (see the smaller of the two figures). By this means the needles are kept at equal distances from one another throughout the operation, and they cannot touch accidentally, and they can be moved about simultaneously inside the nævus so as to bring the whole of it under the action of the current.

It is difficult to formulate a rule for the current to be used, but it is the density of current which is the important point, more so than the actual number of milliampères employed. The current density should not exceed twenty milliampères per inch of positive needle if it is desired to avoid sloughing in a nævus. Thus, with four needles introduced for a distance of one inch, two being positive, a current of forty milliampères would be

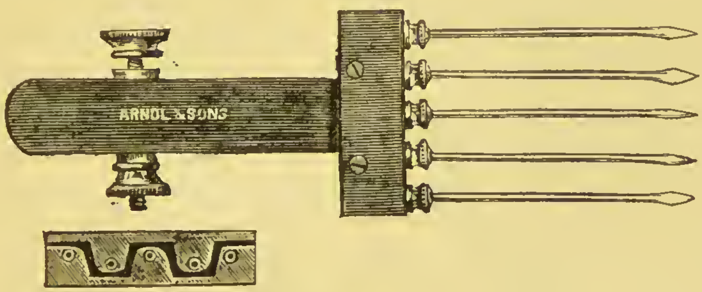


FIG. 122.—Bipolar fork electrode.

amply sufficient, and with twice the number introduced for half that distance the same current would yield the same effects.

The cells of an ordinary portable battery will do very well for the occasional electrolysis of nævi, but as the current required tends to exhaust small cells rather fast, it is better to use larger ones when portability is not essential. The galvanometer must read up to fifty milliampères. From twelve to twenty cells are sufficient.

The usual arrangement of wires for the attachment of the needles is shown in fig. 123. It consists of two parts, (1) a main lead from the pole of the battery, terminating in a binding screw, and (2) several secondary leads or branches, each carrying a needle, and attached to the binding screw of the main lead. The needles should be of platinum. Insulation of the needles is not important, and it is difficult to obtain an insulating coat which does not greatly increase the thickness of

the needle and act as an obstacle to its introduction. Shellac varnish, applied each time, is the best (§ 321). The intention is that the whole of the bare part of the needle must be buried in the nævus, in order that an insulated part may be in contact with the skin, which is then attacked but little, and this diminishes the size of the marks which will be left at the points

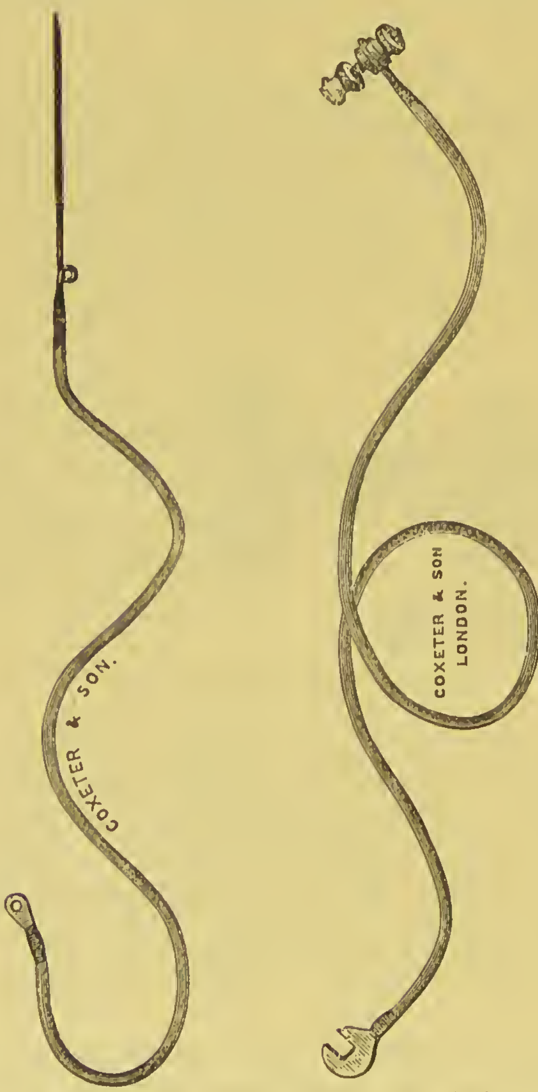


FIG. 123.—Attachment of needles for electrolysis of nævus.

of entry, and for this reason needles are required whose bare points are of varying length. When needles of one pole only are used, the other (indifferent) electrode must be a pad of good size, to diminish as much as possible the density of current at its surface of contact, and also to diminish the resistance.

Care must be taken to prevent any spare needles from touching the patient's skin by accident, or they will corrode it at the point of contact.

The needles are attached to the ends of the wires in various ways. Soldering is much the best. Unions effected by twisting the wire round the needle are bad, for they are apt to break adrift at a critical moment and give rise to shock. With large currents such shocks are undesirable in the case of infants under chloroform.

An anæsthetic should be given as the pain is severe during the passage of the current, though it does not persist after the operation is over.

The needles may be introduced either in a direction parallel to the surface or vertically; the former is the best when the nævus has any appreciable thickness.

In some superficial nævi a multiple puncturing with a vertical needle gives the best results; sufficient skin survives between the punctures to preserve the mark from being truly cicatricial.

The electrolytic treatment of nævus is not so simple a matter as it may appear to be at first sight. Those nævi which can be easily excised should not be attempted by electrolysis, which should be reserved for those which are difficult to do by other methods. If the nævus is very small, that is to say, under a fifth of an inch in diameter, it may be completely destroyed in one sitting, and the resulting scar will not be of any great moment; and here I would urge very seriously the importance of dealing with nævus at the first possible opportunity after birth. Nævi which are quite small at birth are often allowed to grow large before any interference is thought necessary, with the result of disfigurement which might have been prevented by timely treatment. They should always be attacked at once. Unless nævi are large, the first application should aim at complete destruction, or at least the major part of the nævus should be got rid of at the first treatment.

Nævi may spontaneously disappear, but this is a rare occurrence, and the usual tendency of a nævus in the young baby is to grow rapidly. Indeed, after electrolysis, a nævus will often commence to grow afresh, although at the time of operating it seemed to have been completely destroyed. Such reappearance may take place after a nævus had been perfectly healed for over two months. The margin of a nævus is especially prone to

start fresh growth, and must be treated as thoroughly as possible.

Nævus is commoner in females than in males, and it is found on the head and neck more often than upon the trunk or limbs. Out of 173 consecutive cases in the Electrical Department of St. Bartholomew's, 121 were in female, and 52 in male children; in about three-fifths of these the nævus was situated on some part of head or neck. I have once seen a nævus of the ocular conjunctiva. At the anterior fontanelle nævi are commonly met with, and can safely be treated by electrolysis; the needles of course must not be pushed into the brain.

313. **Metallic electrolysis.**—The use of copper needles for electrolysis has been advocated under this name, the intention being to deposit a salt of copper in the nævus or other tissue under treatment. More marked effects can be produced by copper than by platinum needles, and the metal does not appear to leave any permanent stain. The positive pole must be used. Instead of copper needles the ordinary platinum needles can be coated with copper electrolytically in a bath of sulphate of copper, using a piece of copper sheet for the anode and making the needles to be coated the kathode of a battery of one or two Leclanché or other cells; the process only takes a few minutes, and the needles can then be taken out, washed and used for electrolysing a nævus. With copper needles the visible effect is rather different to that of electrolysis with the negative pole and platinum needles, and therefore a certain amount of practice is required before one becomes an adept with the coppered needles; but good results can be had, and especially when a more thorough destruction of a part is desired. The tissues round the needle turn of a dull greenish colour. The negative pole must be used in the form of a pad electrode, as the deposition of copper from the needles takes place only at the positive pole.

314. **Port wine mark.**—This form of nævus can be attacked by a tattooing process, using a fine needle, and inserting it vertically into the skin, the current used must be less than five milliampères, and the application at each point quite brief. There is no need to use several needles at once. The operation should produce minute points of destruction without confluence of the resulting minute scars. The negative pole is best. If a port wine mark be closely scrutinised, the position of many of

the capillaries can be seen, and these are the points into which the needle must be especially directed. The area affected must be treated in a sporadic manner at successive sittings as advised for the removal of superfluous hair. The result is a distinct improvement in the aspect of the surface ; the treatment must be carried out slowly. It is so long a process that it is not often undertaken.

315. **Aneurysms.**—Electrolysis has been tried for the cure of aneurysms, particularly for those which are not suitable for treatment by ligature or compression. In many of the cases recorded, some temporary increase of hardness has followed the operation, but the cures are but few, and the punctures made in the sac walls have sometimes led to hæmorrhage. The piercing of the wall of the aneurysm by the needles, with the consequent risk of bleeding is the chief defect of the operation ; it may be lessened by the use of needles insulated except near their point, so as to limit the electrolytic process to the interior of the aneurysm, and to prevent any action upon its wall.

The method which is generally preferred is to introduce both positive and negative needles into the tumour ; the needles attached to the positive pole become corroded if they are made of steel, but this is not an objection, for coagulation is promoted by the salts of iron so produced. Ciniselli* has collected twenty-three cases, of these six recovered, sixteen died, and one case disappeared from observation. Some of those reported as cured had relapses a few months later. See also *Brit. Med. Journal*, 1890, vol. i., p. 1276, for a report of successful results after thirteen sittings in a case of aortic aneurysm.

As far as can be made out from the details furnished, the electrolysis of aneurysm requires large currents and long sittings. Twenty, thirty, or forty cells have been used, and the application continued for half an hour or more. Assuming the internal resistance to have been 100 ohms (it may have been much lower), and putting the electromotive force of the cells used at one volt a piece, then twenty cells would give a current of about 200 milliampères, and forty would give twice as much. This current if continued for half an hour, would be sufficient to set free a considerable amount of electrolytic gases, and in some of the cases we read that the tumours became resonant to percussion after the operation. The free acids and alkalies pro-

* "Treatment of Thoracic Aneurysms by Electro-puncture," Milan, 1870.

duced by the electrolytic separation of the neutral salts of the blood would probably soon recombine in their passage along the blood stream. The clotting set up in the aneurysm is soft and diffluent.

316. **Stricture of the urethra.**—Modern writers on this subject refer to Crussel, 1839, as the first to use electrolysis for the cure of this condition, and to Mallez and Tripier* as the first to practise it systematically.

The electrical treatment of any disease, in order to justify its existence, must offer results which are superior to those which can be had in other ways, and apparently surgeons do not find it necessary to use electrolysis in stricture of the urethra because they can obtain the required results without it.

In a paper read at the Annual Meeting of the British Medical Association, in 1886, by Dr. W. E. Steavenson, the following account of electrolysis of stricture occurs :—

"For the treatment of stricture of the urethra, the electrodes we have used are catheter-shaped gum-elastic bougies, ending in a metal nickel-plated piece connected to a binding screw on the handle. The indifferent electrode is placed upon the patient's back if he is in the recumbent position, or it may be placed on any other convenient part of the body. The metal plate is made positive.

"An ordinary bougie is first passed down to the stricture, and by its means the distance of the stricture from the meatus is ascertained, and a mark made on the bougie. It is then found out what sized bougie will pass the stricture. Say, for instance, it is ascertained that a No. 3 bougie (English) will pass; a No. 5 electrode is then taken and passed down to the stricture, where it is arrested. It can be made certain that the electrode is arrested at the stricture by previously marking it, after measurement and comparison with the bougie first passed. When the electrode is in position against the stricture, it is connected with the negative pole of the battery, the circuit is closed and the current gradually increased without breaks until the maximum strength is reached that it is intended to employ, namely, about five or six milliampères. The electrode is kept gently pressed against the stricture in the direction of the ordinary course of the urethra. No force is used, but the

* "De la guérison durable des rétrécissements de l'urèthre par la galvano-caustique chimique," Paris, 1867.

current is allowed to do the work. The surgeon has to keep his attention continually applied to the electrode, so as to guide it in the right direction, otherwise a false passage may be dissolved into the side of the urethra. Therefore skill in passing a catheter is a requisition. In the hands of a surgeon who knows his way into the bladder, a false passage is not more likely to be produced than is the case in passing an ordinary catheter. The electrode is to be kept gently pressed against the stricture in the normal direction of the urethra until, from the dissolution of the obstacle in front of it, it passes into the bladder. The current then should immediately be cut off, and the bougie withdrawn. The duration of the operation depends upon the density of the stricture and the strength of the current used."

317. **Other strictures.**—Electrolysis has been recommended for stricture of the œsophagus by most writers on medical electricity. Stricture of the rectum can also be treated by means of electrodes shaped like rectal bougies, which are connected to the negative pole of the battery. A bougie is selected of a size rather larger than the stricture, to which it is applied firmly. A current of five or ten milliampères is passed. After a variable time the stricture gives way, and the bougie passes through it. The time of each operation may be from ten minutes to half an hour. The operation is repeated with a larger instrument in ten days or a fortnight. No anæsthetic is required.

318. **Eustachian obstruction.**—In the *Lancet* for Nov. 24,

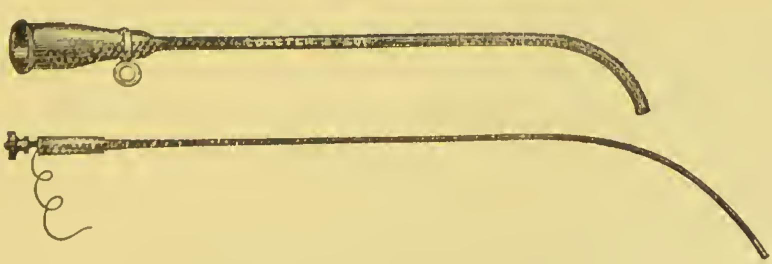


FIG. 124.—Eustachian catheter electrode.

1888, a paper on electrolysis of the Eustachian tube was published by Mr. Cumberbatch and Dr. W. E. Steavenson. The authors described their methods as follows:—"The instrument consists of a vulcanite Eustachian catheter and an electrical bougie (fig. 124); the bougie is made of a fine flexible copper

cord about seven or eight inches long, insulated by vulcanite to within an eighth of an inch of its end. The ends are soldered into a nickel plated cap. The bougie is small enough to pass along the catheter, and exceeds it in length by about an inch. The handle end of the bougie is provided with a binding screw, to which the insulated copper wires are also attached, for the purpose of connecting a rheophore from the battery. On this end of the bougie an inch is marked off divided into eighths. Each eighth of the inch passes into the catheter as one-eighth protrudes at the other end. It is therefore possible to tell, when the catheter is in the orifice of the Eustachian tube, how much of the bougie is in the canal. On the catheter there is a metal ring, or some other mark, to indicate the direction of its end when it is being inserted.

"Electrolysis of the Eustachian tube is performed in much the same way as the electrolysis of the other mucous passages. A pad connected with the positive pole of a battery is moistened and placed at the back of the patient's neck. The Eustachian catheter is then passed along the nostril and guided into the tube; the bougie already attached to the negative pole of the battery, is passed along the catheter and Eustachian canal as far as it will go, until it meets an obstruction. The circuit is then closed. A galvanometer should be included in the circuit, and the current gradually increased up to four milliampères. A frizzling noise will be heard by the patient in his head, and the operator, by approaching his ear to the catheter, may hear the crackling produced by the breaking of minute bubbles of gas. The electrolysis is kept up for four minutes, and usually before the expiration of that time, if it is possible that the obstruction can be removed, it will be found that the bougie can be pushed on for a small distance, sometimes for its full length. Generally on the first occasion the Eustachian tube is rather sensitive, but it seems to acquire toleration for the process, and at no time is so much discomfort experienced as might be expected. The operation has now been performed a large number of times without any unpleasant experiences, nor has the treatment caused any pain, either at the time or afterwards.

"In favourable cases there is an immediate improvement in the hearing, as tested by the greater distance at which a watch can be heard after the passage of the instrument; the distance

at which it is heard may be doubled. In other cases the results are not so good, partly from the difficulty of reaching the Eustachian tube, and partly no doubt from other causes." This method has fallen into disuse.

319. **Lachrymal obstruction.**—In a paper by Mr. Jessop and Dr. Steavenson,* an account is given of ten cases of lachrymal obstruction treated by electrolysis. The advantage of the method is again due to the ease with which the action can be confined to the exact parts needing treatment. The instrument used by them is a platinum probe curved. The operation is very simple; the current required is small, two to four milliampères being sufficient, and the duration is thirty seconds. No anæsthetic is needed; the probe must always be negative, the positive pole being the usual pad indifferent electrode. Two or three sittings suffice to produce cure of the obstruction. The cases related are confined to those in which the obstruction was at the punctum or in the canaliculus, and not in the sac itself. The operation is simpler than the slitting up of the canaliculus, and the improvement is permanent.

320. **Goitre.**—The treatment of simple goitre by electrolysis has been recommended by Dr. J. Duncan,† who states that he had operated on a goitre of considerable size, and that it shrivelled up quickly after one application, leaving only a tiny knot of scar tissue. In other cases in which he had operated by electrolysis he had also obtained successful results. But it does not appear that much work has been done in recent years in the treatment of simple goitre by electrolysis.

321. **Exophthalmic goitre.**—Electrolysis of the enlarged thyroid gland has been warmly recommended by Dr. G. Vaudey, of Marseilles,‡ as a successful method of treating this disease. His views are based upon the need of reducing the activity of the gland, and he claims that this can be satisfactorily effected by electrolysis, and that the degree of reduction of the gland can be finely adjusted to suit individual cases. He considers that the needles used for the electrolysis must be insulated where they pierce the skin, and he advises the insulation to be applied by the surgeon a short time before the operation, by dipping them into a solution of shellac in alcohol of 80 per cent.

* *Brit. Med. Jour.*, 1887, ii., p. 371.

† *Ibid.*, 1888, ii., 984.

‡ *Annales d'électrobiologie*, 1899, p. 182.

strength. The proportion of shellac to alcohol is as one part to five. Steel needles are used and they are connected to the the positive pole, the end is left bare for the distance of one-fifth of an inch in order that the electrolytic action may be localised in the actual thickness of the thyroid gland itself, and there is no electrolysis in the skin and superficial tissues. The use of varnish protects the skin from the risk of disfigurement by black marks due to oxide of iron deposited from the iron of the needle. Dr. Vaudey states that an anæsthetic is not necessary, and he reports several cases in which excellent results, both upon the general state of the patient and upon the enlarged gland itself, followed his treatment.

322. **Xanthelasma palpebrarum.**—The little yellowish patches on the eyelids which are known under this name can be electrolysed with success.

The negative pole should be used, and the electrode should be a steel needle. The patch is best treated by holding the needle vertically and electrolysing it all over with a succession of punctures which need not penetrate very deeply.

Villard and Bosc,* in writing on this subject have given the following account of their method:—The treatment is carried out at one sitting; for small plaques of 4 mm. or 5 mm. a single puncture only is required, for larger ones, the patch is divided into areas which are successively punctured. The important point is to neglect no part, and even to go beyond the limits of the diseased area. A single or double needle (fig. 119) having been thrust into the skin of the plaque, and parallel to the surface, for a distance not exceeding 10 mm., the circuit is closed and the current slowly increased, with a rheostat from zero up to six or eight milliampères, as registered on a galvanometer. After two to four minutes it is gradually reduced again to zero.

During the electrolysis the skin of the plaque becomes distended with gas and greenish in colour, while the needles are surrounded by a frothy ring. The electrolysed skin forms a superficial slough which comes away eight to fifteen days later. A dark crust then forms, which falls off two or three times before cicatrization is complete, about three or four weeks later. As the immediate result the xanthelasma has disappeared, and in its place is a little cicatrix which is whitish, smooth, supple,

* *La clinique ophthalmique*, 1903.

and hardly to be distinguished from the surrounding healthy skin. Regarding the remote results, it is found that no relapse takes place, provided the patch has been thoroughly treated at its edges. The authors conclude with the following words:—"Electrolysis is the treatment to be preferred in all cases of xanthelasmata of the eyelids, whatever their site, number, or extent; excision being an exceptional treatment. It entails no loss of substance (the slough being limited to the superficial layers of the skin), no deformity, and gives a perfect æsthetic result. Finally, the cure is complete and definite on condition that the electrolysis has reached and destroyed every part of the xanthelasma and has even slightly overstepped the margins of the neoplasm."

323. **Electrolysis of uterine fibroids.**—Since the publication by Apostoli of his method of treating fibro-myoma, an immense amount of literature has been produced on the subject. Much has been said both for and against his treatment,* and the enthusiasm which was at first shown in his favour by many writers, has to a large extent been followed by a reaction. There is no doubt that electrolysis may hold a place in the treatment of fibroids, because in many cases it affords great relief to the symptoms of the patient, even if it does not effect a radical cure of the disease. What has been written above of electrolysis in stricture of the urethra applies also to the electrical treatment of fibroids, namely, that the electrical method competes with other surgical modes of treatment without offering any decided advantages, and in consequence it is of secondary rather than of primary importance.

In 1882, Apostoli communicated a paper to the Académie de Médecine, in which he described his method of procedure. He recommended an internal positive electrode of platinum, and an abdominal electrode (negative) of moist china clay of large surface, and a continuous current of sixty to seventy milliampères, applied for from five to fifteen minutes. Sittings were repeated once or twice a week.

The action of the current was to produce destruction of the uterine mucous membrane. The results were to reduce the size of the uterus, and to decrease the hæmorrhage. The destruction of the mucous membrane is followed by a healthy process

* See the medical journals, 1888, 1889, and publications by Drs. Steavenson, Bartholow, Keith, Massey, Engelmann, and many others.

of repair, by a process of involution, and by a cicatrisation which checks the metrorrhagia.

Bergonié and Boursier have published the notes of a hundred cases in which they carried out Apostoli's treatment for fibro-myoma, and they give the following summary of their views*:—"The electric treatment of fibro-myoma is undoubtedly efficacious as a palliative method of treatment. When hæmorrhage was the chief symptom complained of 90 per cent. were relieved. The general state of health was improved in 79 per cent., the symptom of pain was relieved in 50 per cent., while a decrease in the size of the tumour was observed in ten per cent. only.

324. **Extra-uterine fœtation.**—Attempts have been made to arrest the progress of extra-uterine fœtation by electrical treatment, and cases which appear to have been successful have been recorded.

In the St. Bartholomew's Hospital Reports, vol. xix., 1883, Dr. Matthews Duncan and Dr. Mason published a paper on extra-uterine fœtation, with an account of one case in which the pregnancy had lasted five months and the fœtal heart was audible. Electrolysis was practised on two occasions with a fortnight's interval, but the fœtal heart was not arrested on either occasion. Other means of destroying the fœtus were then employed, and the patient died of peritonitis a week after the second sitting; post-mortem the fœtus was found very considerably macerated, this was considered to have been due to the electrical treatment.

Dr. Percy Boulton† has also published a case of early (six or eight weeks) extra-uterine fœtation, where electrolysis proved fatal from peritonitis, but there was no post-mortem examination to show what changes had been set up in the tumour. These cases show that the treatment by electrolysis with the insertion of needles into the tumour is dangerous.

Mr. Lawson Tait and other speakers at the Brighton meeting pointed out that very often tubal pregnancy may undergo spontaneous cure. It is very likely that some of those said to have been cured by induction coil shocks were really cases of this kind, because it is difficult to see how a moderate induction current, diffused through the large sectional area of the abdo-

* *Arch. d'électricité médicale*, 1893, 211.

† *Brit. Med. Journal*, April, 1887.

men, could exert any effect at all upon the tissues of a young fœtus, though it might possibly produce some mechanical compression by setting up tonic contraction of the muscle fibres in the Fallopian tube round it.

325. **Cancer.**—The treatment of cancerous growths by electrolysis has been proposed, and electrolytic treatment can be used to produce sloughing of parts of a cancer, and the method is sometimes useful, when nothing else can be done, because the pain of the cancer is often much diminished after electrolysis, as has been observed by Althaus.

Some years ago Inglis Parsons* advocated the use of electrical discharges as a possible means of arresting the growth of cancer. The method was to introduce needles into and around the growth, and to apply momentary currents of large magnitudes. On several occasions currents up to 600 milliampères were employed, and favourable results seemed to have followed, but the method was not free from danger.

More recently Dr. Betton Massey,† of Philadelphia, has employed metallic electrolysis (§ 310) in cancer cases. In his method actual destruction of the central portions of a superficial malignant growth is combined with a diffusion of ions of a metal such as zinc or mercury into the peripheral parts, and he has been able to observe that there is an undoubted effect in arresting the malignant growth in a zone lying outside the portion which has been destroyed by sloughing as a result of the treatment. Dr. Massey attributes this to the action of the metallic ions which have diffused away from the electrode, and he lays especial stress upon the need for allowing a sufficient duration of time to the electrolytic treatment, in order to permit of a sufficient diffusion, as this is a comparatively slow process.

The currents used have ranged from 350 to 1,800 milliampères, the duration of the application lasting one hour or even longer.

A significant note of Leduc,‡ on the subject of treatment by the introduction of metallic ions, may be mentioned in connec-

* *Brit. Med. Journal*, 1889, i., 936; *Medical Press and Circular*, 1890.

† "The Treatment of Cancer by Electrical Destruction and Regional Sterilisation through the Cataphoric Diffusion of the Electrolytic Salts of Mercury and Zinc." *An International System of Electro-therapeutics*, London, Henry Kimpton, 1902.

‡ *Arch. d'élect. médicale*, 1903, p. 734.

tion with this mode of treatment. He relates a case in which a rodent ulcer of five years' standing was completely cured by one application of electrolysis by means of a zinc anode, and a layer of cotton-wool soaked in a one per cent. solution of zinc chloride. A current of 12 milliampères was applied for ten minutes.

CHAPTER XVI.

Cautery and Lighting Instruments. The Electro-Magnet.

The galvano-cautery. Batteries for cautery purposes. Accumulators. Wires and leads. Lamps. Batteries for lamps. Rheostats. The antrum lamp. The cystoscope. The panelectroscope. The electro-magnet.

326. **The galvanic cautery.**—The forms of galvano-cautery in common use are numerous, but their plan of construction depends upon one general principle. The cauteries used for most operations consist of small loops of platinum wire mounted on straight or curved copper supports, which are insulated from each other, and then bound together to form a convenient stem (fig. 125). These fit into a handle provided with binding screws

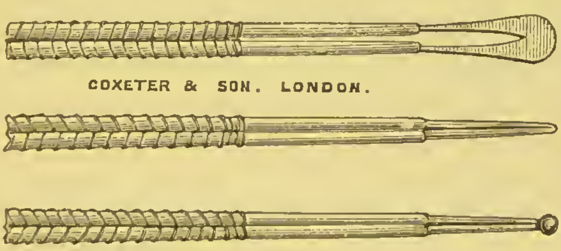


Fig. 125.—Cautery points.

and a key for easily opening and closing the circuit. The platinum loops, having a relatively high resistance, become heated by the passage of the current. The figure (fig. 126)

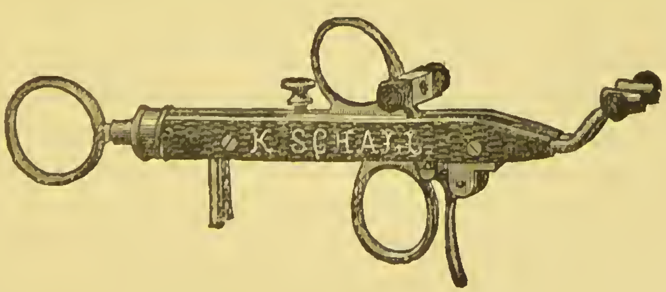


Fig. 126.—Schech's handle.

shows an usual form of handle, known as Schech's, which is made in two sizes. For most operations the shorter handles

are more convenient than the large size, which is too unwieldy for delicate manipulations.

For fine work a very good handle is made in the shape of a metal pencil case (fig. 127). Connection is made by a twin

FIG. 127.—Cautery handle.

wire with a concentric plug which fits a socket at the end of the handle, the switch is a ring of metal sliding over a piece of ivory. This form of cautery handle is much the most convenient for small sized burners, and whenever burners mounted on long stems are not required.

The current which heats the platinum points heats the cautery mounts as well, in a less degree; the current, therefore, should only be left on when the cautery is in actual use. The insulation of the supports is effected by a thick waxed thread twisted round them in racking turns, which keeps them from touching, although binding them together, and forms a sufficient means of insulation, provided that care be taken to avoid prolonged overheating.

Besides the simple platinum loops, cutting instruments of various shapes are made by hammering the platinum flat or by bending it in various ways. Where a larger incandescent surface is required, a loop or spiral of platinum supported in grooves on a porcelain mount is made, the porcelain then becomes heated to redness as well as the platinum (see fig. 128).

FIG. 128.—Cautery with larger incandescent surface.

Different thicknesses of platinum wire are used, and accordingly the current required varies greatly in different cauteries.

Sometimes a long loop of wire is used as an ecraseur, being adapted cold to the part to be removed, and then heated, and a screw can be mounted on the handle figured above for gradually drawing up the wire loop when it is hot. Steel wire is generally used on account of its cheapness, but platinum is the best. It is as well to mention that the temperature of a cautery must not be allowed to rise above dull redness. At a white heat the cauterising action is so rapid that searing of the surface does not

take place, and hæmorrhage may follow as profusely as after division of the tissues by a knife. A large number of modified forms of cautery and mount will be found in the instrument makers' catalogues. The resistance of the cauteries just described may vary from ·025 to ·04 ohm.

The current required to bring the platinum loops to redness varies between eight or ten ampères for the smallest, to upwards of twenty for the larger ones.

Still larger currents are required for a few cauteries, which have been constructed for special purposes.

In the prostatic cautery of Prof. Bottini* the part to be heated consists of two strips of platinum, each 20 mm. × 8 mm., which lie side by side in the concavity near the beak of an instrument, which is shaped like a vesical sound. The current passes along one strip and returns by the other. The large mass of the platinum makes the resistance of the part to be heated remarkably low, about ·0005 ohm, and consequently an immense current, amounting to fifty ampères, is required to raise it to a red heat. Such a current as this taxes any portable battery to the utmost. This instrument is used for the radical cure of the symptoms caused by enlarged prostate, and its use has been advocated in this country by Mr. Bruce Clarke,† who has employed it successfully on several occasions.

327. **Cautery batteries.**—The batteries of small cells which are used in medical treatment are arranged for high electromotive forces with the minimum of weight, and their internal resistance is of little importance as small currents only are wanted under those circumstances. For cautery purposes the conditions are quite different, and the small medical cells are therefore unsuitable. Large bichromate cells have been much used for cautery purposes, although they are rather troublesome to maintain, because they may be made to yield a large current for brief periods. Fig. 129 shows a form of this battery which is in general use. It is so arranged as to permit of use as a two cell battery with pairs of cells in parallel for cautery purposes, or as a four cell battery for electric lamps, which need a rather higher electromotive force than is required for cauteries. In places where storage cells cannot be used this form of cell must be had recourse to.

* *Brit. Med. Journal*, 1891, vol. i., p. 1121. Description and figure.

† *Proceedings of the Medico-Chirurgical Society*, Jan. 1892.

A very convenient outfit for cautery and also for surgical lamps is a four celled accumulator. It may be fitted with a switch for rearranging the cells in two pairs in parallel, and can then be used either as a two cell accumulator of double cells for

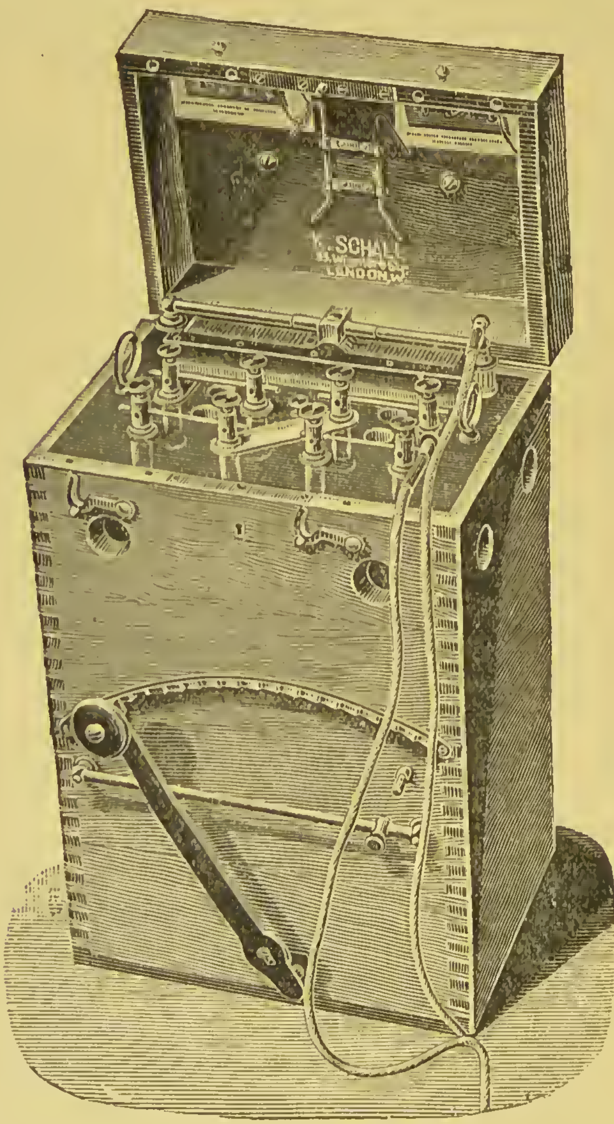


FIG. 129.—Bichromate battery for electric lamps and galvano-cautery.

cautery purposes, or as a four celled one for lamps taking up to eight volts. There is no special advantage in this except for heavy cautery work, and the extra connections are sometimes troublesome. Figures 130 and 131 show such an apparatus, which is constructed for surgical purposes. It weighs fifteen

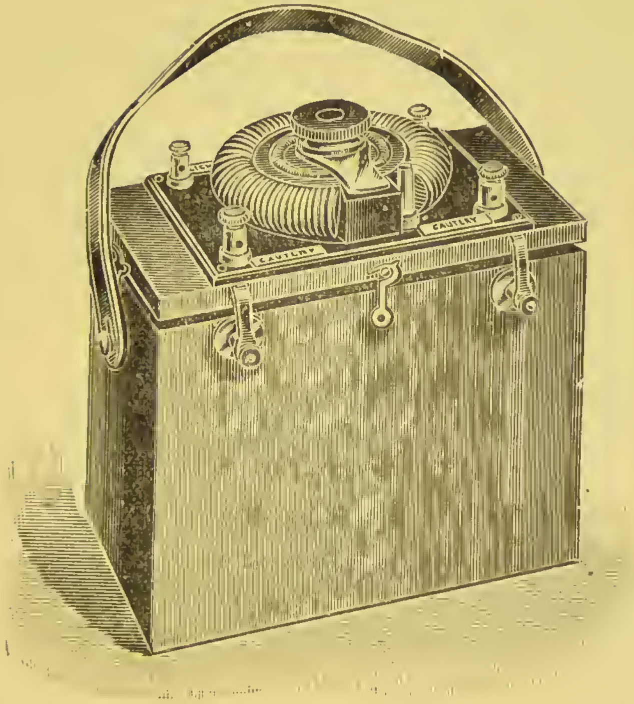


FIG. 130.—Accumulator for lamps and cauteries.

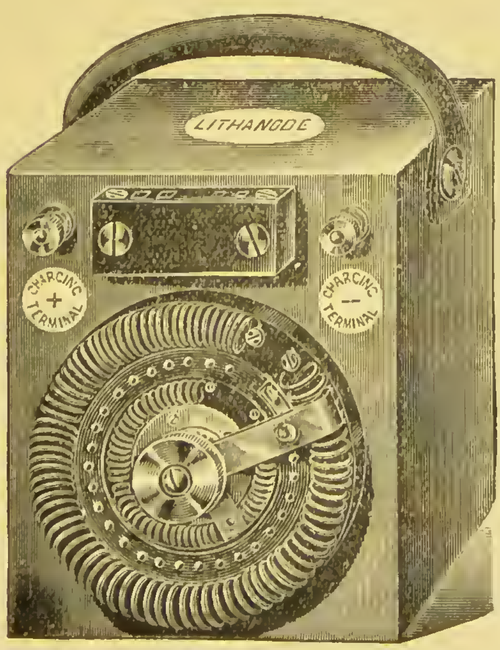


FIG. 131.—Accumulator for lamp and cautery work.

pounds, and is provided with two resistances, one for lamp and one for cautery use. The connections are so arranged that the lamp resistance is in series with the lamp terminals and the cautery resistance with the cautery terminals.

328. **Electric light mains.**—The use of the electric lighting mains for lamps and cauteries was discussed in Chapter V.

329. **Conductors.**—It is important to use thick copper wire conductors in cautery work because the resistance of the whole circuit being very low, that of the conductors becomes an important fraction of it, and may determine whether the cautery will be properly heated or not.

It may be useful to give an example here of the calculations to be made in arranging the apparatus for heating a cautery. Suppose that a cautery having a resistance of ·04 ohm and requiring a current of 20 ampères is to be heated, and that the battery power available consists of two accumulator cells in series, each with an electromotive force of two volts, the internal resistance of each cell being ·01 ohm.

To obtain a current of twenty ampères from four volts the total resistance in circuit may amount to ·2 ohm. If proper leads are used, their resistance will be ·0014 ohm per metre. We will suppose each wire to be 1·5 metres in length, their total resistance will then be ·0042 ohm. The necessary resistance in circuit in this case (resistance of battery, of leads, and of cautery) therefore amount to $\cdot02 + \cdot0042 + \cdot04 = \cdot0642$, or say ·065 ohm. This leaves a margin for faulty contacts and for rheostat of ·135 ohm, and the cautery would be adequately and easily heated.

But, now suppose that the leads are of a size having a resistance of ·04 ohm per metre. This will give a total resistance in circuit of $\cdot02 + \cdot12 + \cdot04 = \cdot18$ ohm, leaving a bare margin of ·02 ohm for faulty contacts. This would be insufficient, as there are several points of contact, and a small degree of oxidation or tarnishing at any one of them would prevent the cautery from heating, add to which there would in all probability be a considerable amount of heating in the leads, which would certainly increase their resistance, and might destroy their insulation. These examples show the importance of using conducting wires with plenty of copper in them, and of keeping all contacts and binding screws scrupulously clean and bright. A rheostat must always be included in the circuit when a cautery is to be

heated, if this precaution is neglected, there will be much trouble from over-heating and fusing of the platinum loops.

330. **Lamp instruments for diagnosis.**—Small incandescent lamps have been adapted to laryngoscopes, ophthalmoscopes, otoscopes, vaginal specula and other instruments (figs. 132 and 133). They are not used very universally, because in many cases the maintenance of the battery is troublesome, and because other sources of illumination are sufficient.

On the other hand certain new exploring instruments have

FIG. 132.—Laryngoscope with electric lamp.

come into use whose value depends entirely upon the principle of the electric lamp. The cystoscope and the gastroscope are examples of this form of lamp instrument. The small lamps used in diagnosis are of about one candle power and vary a good deal in their resistance (5 to 20 ohms), and therefore the electromotive force required to bring them to incandescence varies also. If the filament is slender, or if it is long, their resistance is high, if it is short or thick, their resistance is less

FIG. 133.—Ophthalmoscope with electric lamp.

high. A long slender filament may require eight or ten volts to light it properly, while a shorter one will glow with six volts. The rate of consumption of energy by an incandescent lamp is about four Watts per candle. Thus if a ten volt lamp absorbs ·4 of an ampère, a six volt lamp would require ·7 ampère to give the same light. When the current is supplied from a portable battery it is best to use the higher voltage lamp for the sake of the advantage of having to provide a smaller current, 400 milliampères ·4 ampère being more within the range of a

portable battery than 700 milliampères, and the battery will therefore run down less rapidly. On the other hand a greater number of cells will be required to provide the higher voltage. It would be a convenience if all small surgical lamps were made for one and the same voltage. As the four cell accumulator of eight volts is the type of battery most generally useful, lamps should be chosen as far as possible to incandesce brightly with this electromotive force.

Among primary batteries useful for lighting small lamps the bichromate cell is convenient if no means of recharging accumulators are available. Dry cells may be used for this purpose, but do not keep well or last long if used much for lamps. Six dry cells fitted in a plain oak box are supplied by Mr. Schall with a simple form of rheostat, and they may be trusted for a fair number of examinations. It should be borne in mind that dry cells gradually fail as they get old, whether they be used or not. From three to six months may be taken as the duration of usefulness with dry cells. An improved form of Leclanché has also been introduced for this purpose, and answers well if portability is not required.

If accumulators are used, small ones may be had for the sake of portability. Small accumulator batteries are put up by several electrical instrument makers and serve well for surgical lamps (see figs. 130 and 131). The small sizes naturally require recharging more often than the large ones, but this is not an objection, because all accumulators are better for being recharged at least once a week, and the capacity of the small cells is sufficient for lighting a cystoscope or similar lamp for several hours. If the small accumulators can be recharged at home from the mains without trouble they are extremely convenient, but this convenience is lost if they have to be sent away every time to be recharged.

As the different forms of small lamp vary a good deal in their resistance, a regulating resistance in the circuit is necessary to compensate for these variations, as without it some lamps would be overheated and would quickly be destroyed. Suitable resistances are supplied with many of the types of portable accumulator now in the market. The resistance required for regulating the lamps need not be more than about six or eight ohms. As the current to be carried is only about half an ampère in a well made lamp the resistance is easily made of a few turns of fine

German silver wire. Resistances are equally important for cauteries, but there they have to carry large currents and must be made of thick wire; however, their total resistance need not be so great, for a variable resistance of half an ohm is sufficient to modify very greatly the current in a cautery circuit (see § 79).

For ordinary purposes of illumination an electric lamp can be adapted to a wall bracket as shown in fig. 134. By employing

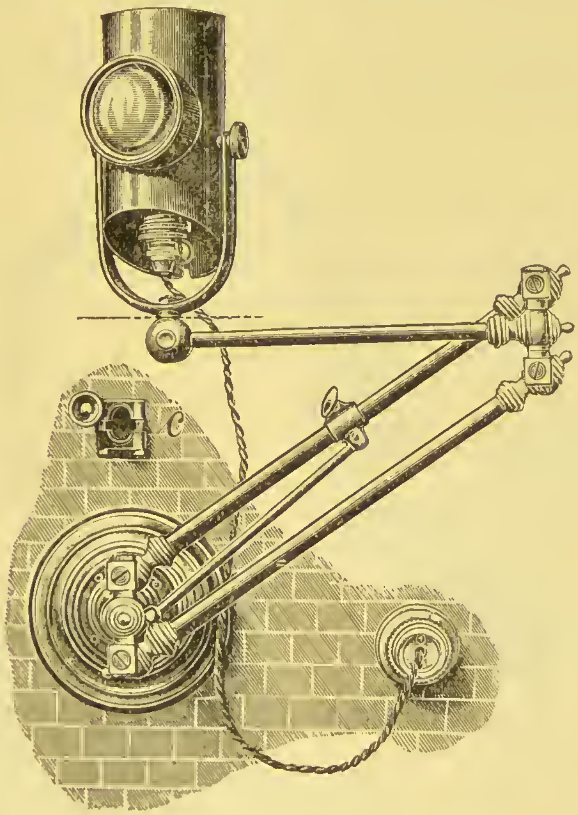


FIG. 134.—Electric lamp on wall bracket.

the Nernst* lamp, and a ground glass pane behind the bull's eye, an uniform light can be obtained, with little or no irregularity from the image of the incandescent filament.

Another convenient form of exploring lamp is shown in fig. 135.

FIG. 135.—Exploring lamp.

* The Nernst lamp has a short rod of the oxide of one of the magnesium group of metals in place of a carbon filament, and glows with a whiter and more brilliant light.

It is designed in such a way as to be kept clean and aseptic without any difficulty. It may be left in the antiseptic solution until required for use. The attachment to the leads is by a double socket fitting, one wire making contact with the periphery of the tube which carries the lamp, and the other with an insulated lead which passes down the centre. The enclosing tube of glass prevents any burning of the tissues with which it might come in contact during an operation. The stem passes through an indiarubber cork.

A head lamp is useful in many surgical operations. Its present form and arrangement is shown in fig. 136. It was originally de-

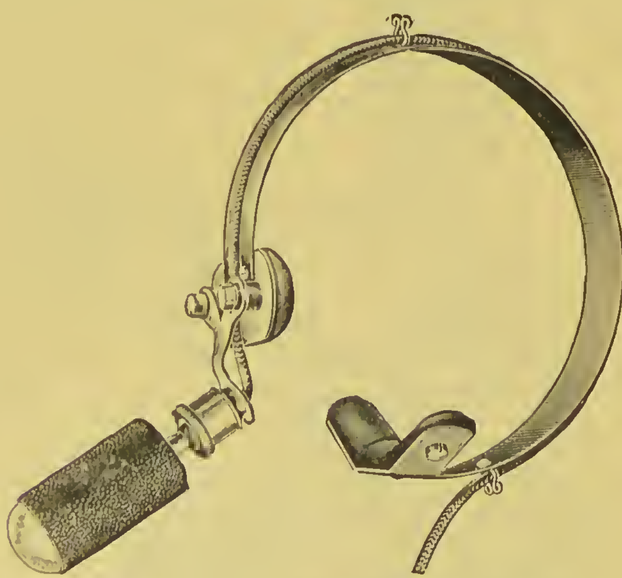


Fig. 136.—Trouvé's photophore, improved model.

signed by Trouvé, and has been modified by subsequent experimenters.

331. **The cystoscope.**—This is an instrument for examining the mucous membrane of the bladder, and it is perhaps the most important and useful of all the electric lamp instruments, because it affords information of the greatest value which cannot be obtained without it. The cystoscope (fig. 137) consists of a beaked sound, in which there is a telescopic arrangement, by which the surface of the bladder is viewed through a small window of rock crystal. A lamp is enclosed in the beak of the instrument and throws its light through another window upon that part of the bladder wall which is in the field of view of the telescope. *B* is a screw for making contact, the wires are

fastened at *CD*. For examining the upper part of the bladder an instrument fitted with a small reflecting prism is used. A certain amount of practice is required to use the cystoscope

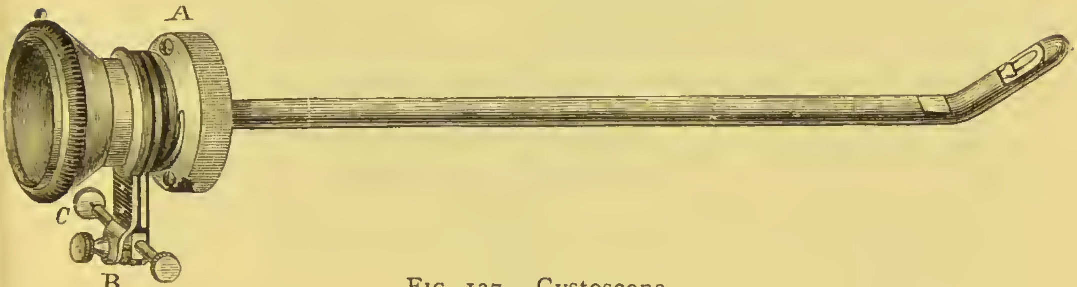


FIG. 137.—Cystoscope.

properly, and to recognise the appearances of the mucous membrane of the bladder in health and in its various morbid conditions. With the dummy bladder (fig. 138) the necessary skill

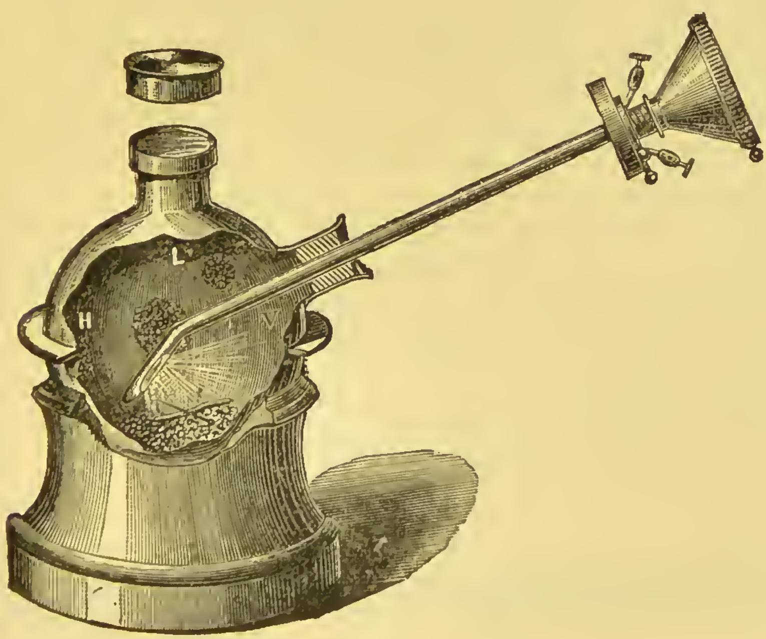


FIG. 138.—Cystoscope and dummy bladder.

can be quickly acquired. For a full account of the instrument and the mode of using it, see Mr. Hurry Fenwick's book on "The Electrical Illumination of the Bladder and the Urethra."* An anæsthetic is not absolutely necessary for a cystoscopic

* London, J. and A. Churchill.

examination, but it is more convenient to employ one, though cocaine may be made to do.

The bladder must contain eight ounces of clear urine or clear water if a proper view of its walls is to be obtained, for if the fluid present be even slightly turbid, the view is very much obscured. If there is bleeding or if the urine is cloudy, the bladder must be washed out with warm boracic lotion until the fluid which returns is absolutely clear. If too little fluid be present in the bladder, the beak of the instrument with the lamp is likely to become buried in the folds of the mucous membrane, and there will be no light. Moreover, in that case the mucous membrane may be burned.

When the bladder contains eight ounces or more of clear fluid the end of the cystoscope lies free in the cavity, and the lamp is kept cool. The instrument must be pushed well home into the bladder and kept there; if it be allowed to work out at all as it sometimes tends to do, the beak may become engaged in the prostate, and then nothing will be seen and the prostate may be burned. The heat of the lamp is unimportant when it is surrounded by a volume of water, but when the lamp lies close against the mucous membrane there is no circulation of fluid round it, and it gradually grows hot and will burn if held too long in one place.

The so-called "cold lamps" are lamps which can be brought to a high degree of incandescence without destruction of the filament, and thus they give out less heat in proportion to the light they afford, but the word cold as applied to them is merely a relative one.

Casper's cystoscope (fig. 139) is provided with a channel for

Fig. 139.—Casper's cystoscope.

introducing a catheter into the ureter; or for drawing off a specimen of the urine while the cystoscope is in the bladder, or for introducing additional fluid into the bladder.

332. **Endoscopes.**—An universal lighting apparatus was introduced by Leiter, of Vienna, under the name of the pan-

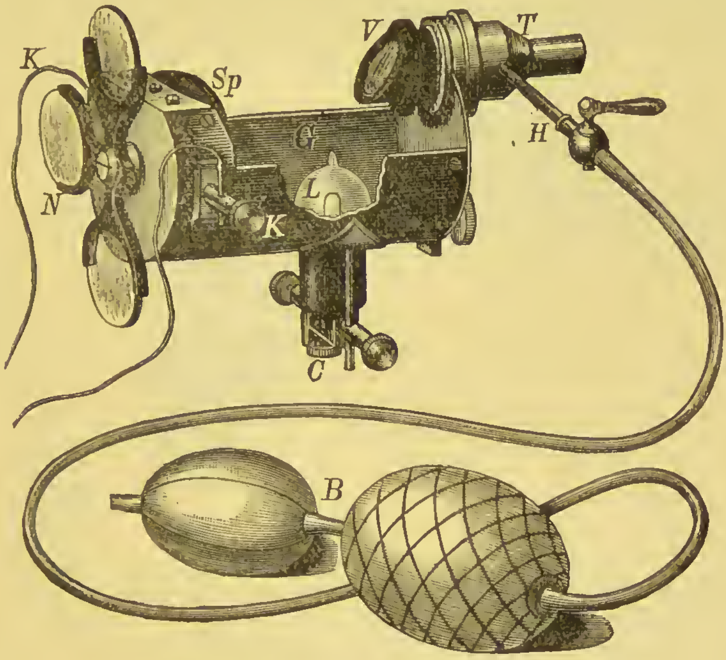


FIG. 140.—Leiter's panelectroscope.

electroscope. It consists of a lantern with a handle and a reflector. The light of the lamp in the lantern is projected along a tube which is inserted into the part to be examined. Tubes of various sizes are adapted to the instrument, which is used mainly as an urethral endoscope, but is also arranged for the examination of the ear, the pharynx and œsophagus, and the stomach. In the figure, *C* is the point of attachment of a handle, *L* is the lamp; *K*, is the point of attachment of the conducting wires. The pump is provided as a means of inflating

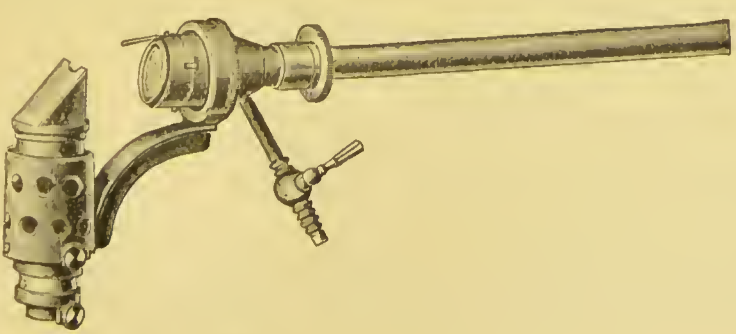


FIG. 141.—Simple form of inflating urethroscope.

the urethra with air, in order to distend its walls, and so to permit a more thorough examination of their surface.

In figures 141 and 142 the light of the lamp is projected along the tube by means of a prism placed directly above the lamp.

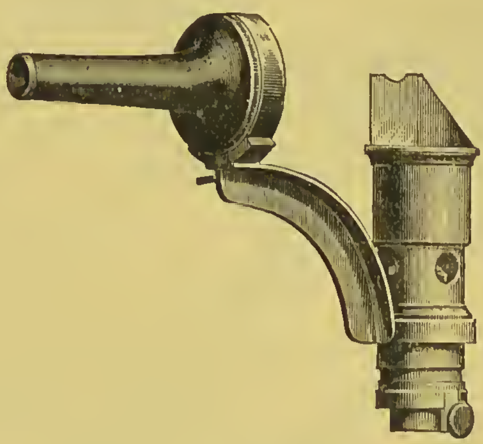


FIG. 142.—Endoscope for the ear.

333. **Transillumination.**—The ease with which small electrical lamps can be brought into close contact with the tissues without fear of burns has led to the invention of new methods of examination which may be conveniently grouped together under the name of transillumination. These methods depend upon the translucency of the tissues, thus a lamp placed in the mouth will light up the tissues of the nose so that these appear luminous and may be examined in a darkened room by the light transmitted.

The larynx may be examined when illuminated from without by an electric lamp placed against the external surface of the neck, at the level of the thyroid cartilage.

The exploration of the antrum of Highmore by means of a lamp placed in the mouth, has excited a considerable amount of interest since the publication by Heryng* of his paper on the subject.

334. **The antrum lamp.**—This instrument (fig. 143) consists of a curved handle fitted with a small lamp, and a plate of ebonite to protect the tongue. To use it the patient must be brought into a darkened room, the lamp is introduced into his

* *Berlin. Klin. Wochens.*, No. 25, Sept. 25, 1889, "L'éclairage électrique de l'antre de Highmore dans le cas d'empyème." See also "De l'empyème latent de l'antre de Highmore," Dr. Jeanty. Bordeaux, 1891, Feret et fils.

mouth, and the lips are closed over its stem; when the current is then turned on the face becomes lighted up by a red glow. If one antrum contains pus a dark shadow is seen on the corresponding side, which is most perceptible just below the eye. The lamp used should have an illuminating power of three or four candles.

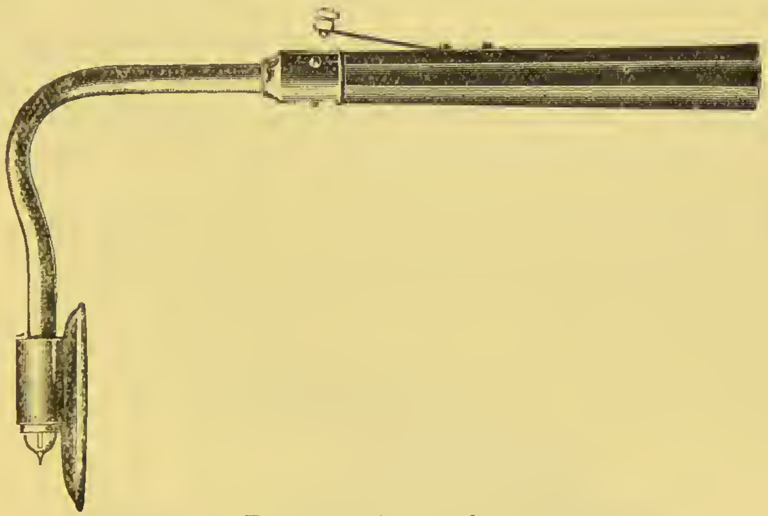


FIG. 143.—Antrum lamp.

335. **The gastro-diaphane.**—This is a transillumination contrivance for lighting up the stomach from within in order to enable an opinion to be formed of its size and position when viewed from without. It consists of a stomach tube of soft

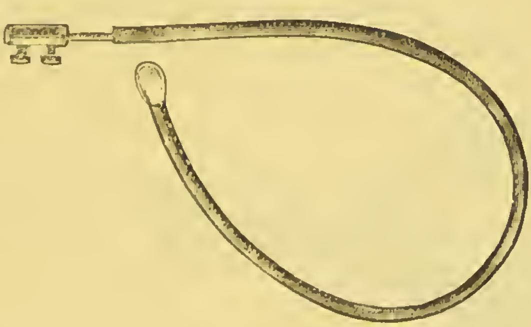


FIG. 144.—The gastro-diaphane.

rubber carrying a pair of wires, and at its end there is a small electric lamp which is protected by an outer cap of glass. Usually the instrument is fitted with a channel for conveying water into the stomach. To use the apparatus the lamp is passed into the stomach; the patient must be in darkness;

when the light is then turned on a luminous glow is seen in the region of the stomach, and the appearance of this in normal individuals should be known in order to judge of alterations due to disease. The stomach should contain eight ounces of water, but no food. Herschell states that the illuminated area of the stomach may be obscured by liver, by intestine containing fæces, or by tumours, and that the lower part only of a normal stomach is translucent, but if the whole stomach is illuminated gastro-ptosis is most likely present, and in this case the illuminated area does not move with respiration. In dilatation of the stomach the upper border of the stomach is not seen, and respiratory movements are present.

For further details as to the use of this instrument in diagnosis, see Herschell's* work already referred to in § 289.

One interesting form of lamp instrument has a rod of glass along which the light of a lamp is conveyed by a series of internal reflections. It is quite cool, and may be used for numerous purposes of exploration (see fig. 145).

FIG. 145.—Glass rod lamp.

336. **Lamps for therapeutic applications.**—Incandescent lamps may be used as a source of warmth as well as of light. Foot warmers fitted with an incandescent lamp instead of the usual hot water have obvious advantages, and the principle may

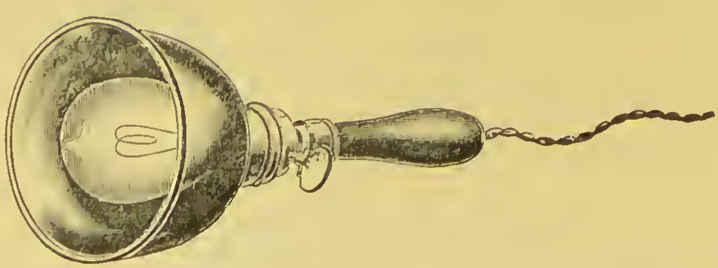


FIG. 146.—Hand lamp for the local application of heat and light.

be extended almost indefinitely for purposes of applying heat continuously to various parts of the body.

Figure 146 shows a form of hand lamp which may be used for

* "Manual of Intragastric Technique."

applying warmth locally for the relief of pain or other purposes, and fig. 147 shows an apparatus fitted with lamps for application to the abdomen.

For these applications of electricity the electric light mains are required, because the amount of energy consumed in them is considerable, and much more than could be conveniently provided from batteries.

It has been claimed that the light given out by incandescent lamps has a therapeutic value above that of the heat they afford, and the use of electric light cabinets in which the whole surface of the body is exposed to the light of incandescent lamps, has been very largely advocated and pushed of recent years, especially by various interested persons. It is certain that the exposure of the body to the light of incandescent lamps is a very

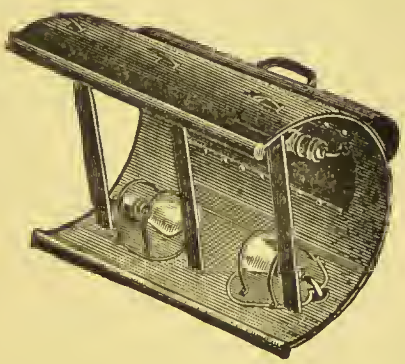


FIG. 147.—Electric light warmer for the abdomen.

convenient way of stimulating the action of the sweat glands, and the effects of the hot room of a Turkish bath may be produced very simply and easily by this means. Fig. 148 shows a "cabinet" for electric lamp baths. The opening at the top is to allow the patient's head to emerge.

The earliest work on the use of incandescent lamps for sudatory purposes was done by Dr. Kellogg, of Battle Creek, in the United States, and his report on the subject was laid before the American Electrotherapeutic Association in 1894. He observed that active sweat secretion began within ten minutes from the time of exposure of the body to the light of the lamps, and found that the average temperature in the bath cabinet was about 80° F. instead of the 140°, or higher, of the hot room of the Turkish bath. He also pointed out that the air was not only cooler but purer in the incandescent lamp bath. It is not

unlikely that the use of electric lamps may supersede the present Turkish bath method of inducing perspiration.

In the treatment of disease the use of light and heat from electric lamps has been considerably developed in recent years. If the extravagant claims made by certain writers be disregarded it still remains that for certain purposes the use of this method of treatment is of value, particularly in the treatment of stiff and painful joints.

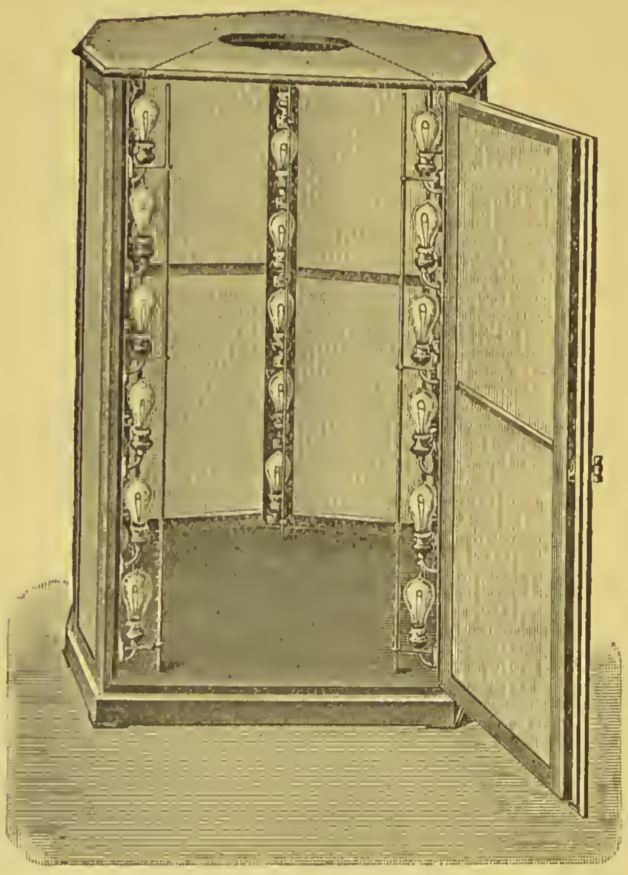


FIG. 148.—Electric light bath cabinet.

337. **The treatment of lupus by light.**—Arc lamps have also been used for therapeutic purposes. With the arc lamp the violet and ultra violet rays are abundant, whereas they are absent or scanty in the light of incandescent lamps. The work of Finsen has firmly established the fact that the concentrated light of the arc lamp, or of the sun, has a curative effect upon lupus, and it is to the labours of Finsen that we owe the introduction of light as a therapeutic agent into medical practice.

Finsen's apparatus consists of a very powerful arc lamp, consuming as much as 80 ampères of current, and the light from the arc is collected by lenses and focussed upon a small area of the affected surface, which is further kept cool and at the same time rendered anæmic by a quartz compressor through which cold water is kept flowing. The object of the compression is to press out the blood from the capillaries of the part under treatment, and so to facilitate the penetration of the light rays to a greater depth than would be possible in the presence of the

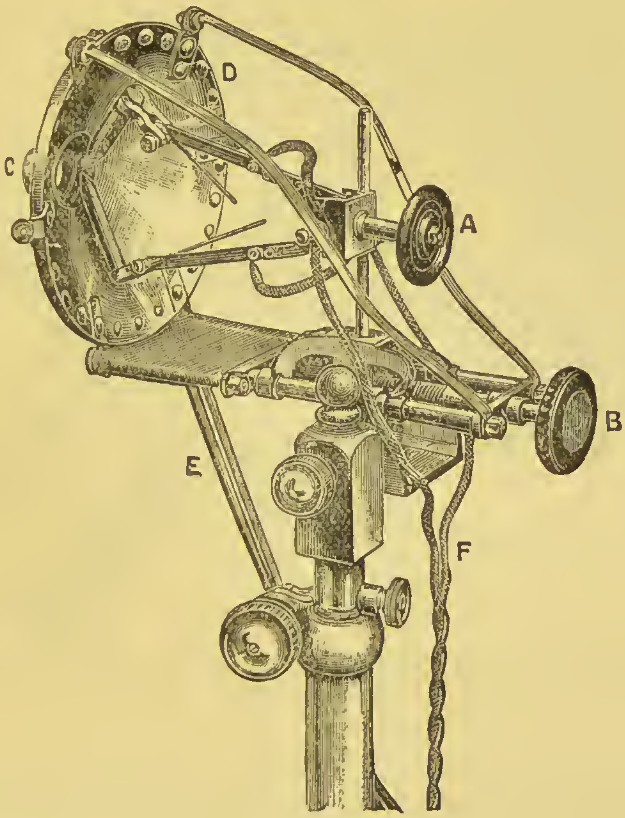


FIG. 149.—Lortet Genoud arc lamp for lupus.

blood, which absorbs the violet end of the spectrum.

The great size and cost of an installation like that of Finsen has led to many attempts to obtain equally good results with simpler forms of apparatus. An arc lamp of moderate size, with a cooling shield and compressor combined, have been extensively used under the name of the Lortet Genoud lamp.

An English modification of this lamp is made by Messrs.

Marshall and Woods,* and is in use in many parts of Great Britain (fig. 149).

In this form of apparatus the lesser power of the lamp is compensated for by the possibility of bringing the source of light very close to the patient. The carbons are close to a shield D of hollow metal in which water circulates. C is a quartz compressor, also water-cooled, which is pressed upon the part to be treated. E and B are for adjustments of the position of the lamp. A is a regulator of the distances between the carbons. F, flexible conductors. The price of the apparatus is £20, without accessories.

Figure 150 shows a sectional view of the interior of the lens,

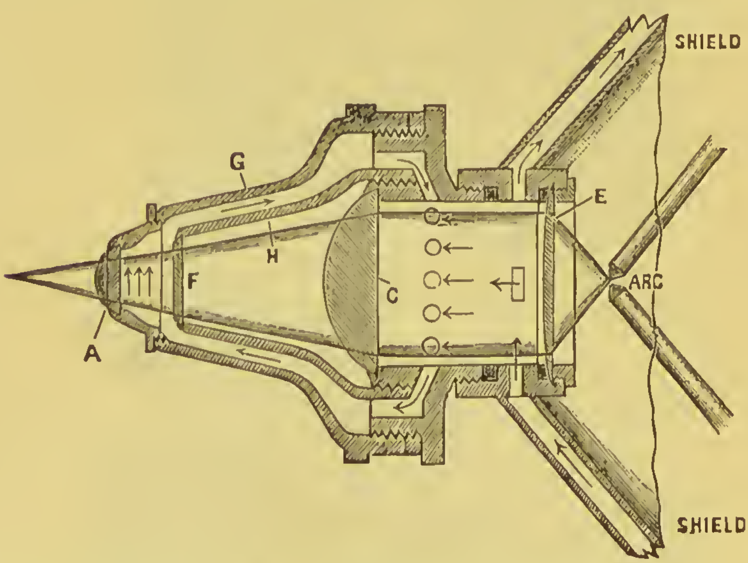


FIG. 150.—Section of lens of the Lortet Genoud lamp, showing water cooling arrangements.

in place in the shield; the rays of the arc are thrown upon, and collected by, the convex lens, E, inserted at the back of the shield, in place of the usual flat lens, they then pass to the condensing lens, C, and are focussed on to the compressor, A, the diameter of the spot of concentrated light being about $\frac{3}{8}$ in. by altering the distance of the arc from the lens, E, this diameter may be increased or decreased to a small extent. The compressor is cooled by the circulating water from the shield, which passes through the apparatus, as shown by the arrows. The lens, F, is merely for enclosing the water in the compressor,

* 2 Gray's Inn Road, W.C.

the space between F and C being air. The apparatus can be easily taken apart for cleaning by unscrewing the metal cones G and H. The distance of compressor from point of shield is three inches. Fig. 151 shows a similar apparatus known as the Finsen Reyn lamp.

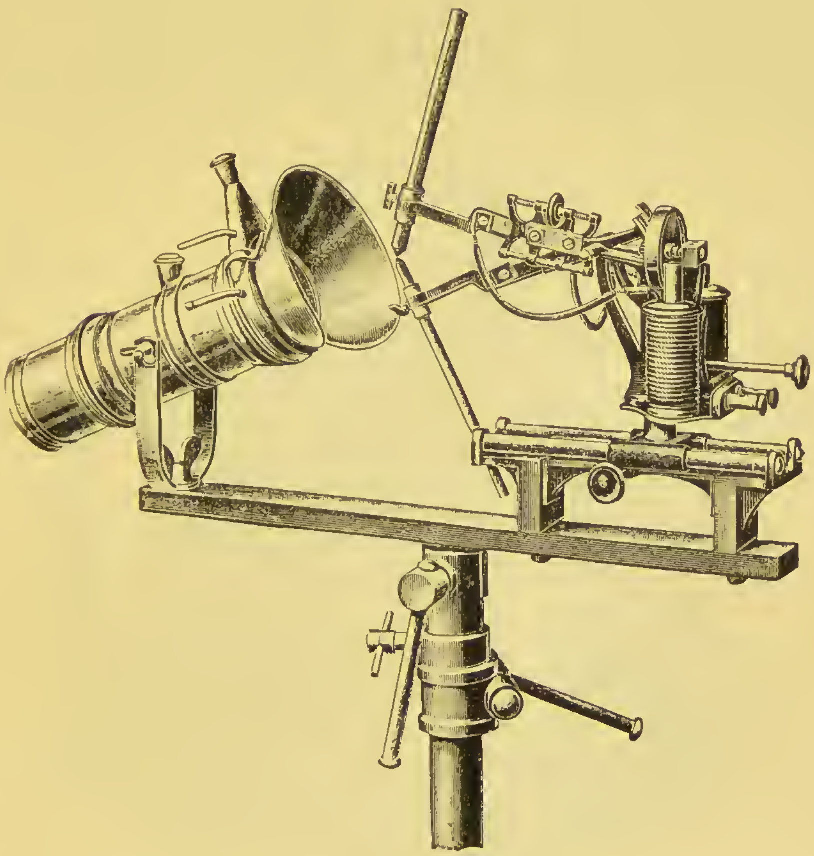


FIG. 151.—The Finsen-Reyn form of lupus lamp.

338. **The condenser spark lamp.**—Although the success of the treatment of lupus by the Finsen method is undoubted, yet its application is extremely tedious.

In the first place the sittings must be of long duration, thirty minutes to an hour, secondly the part treated at one sitting is only about one square inch, and the number of applications necessary to obtain a cure is very great. For all these reasons there have been many attempts to improve upon the method, and it is by no means certain that the unmodified Finsen method of treating lupus will survive the test of time.

Lamps with electrodes of metal to augment the output of ultra violet rays have been devised by several inventors.

The "Dermo" lamp is an arc between electrodes of water-cooled iron. Bang's lamp and that of Broca and Chatin are of somewhat similar character.

The condenser spark lamp known as the St. Bartholomew's lamp, made by Mr. Leslie Miller (fig. 152) makes use of the well known physical fact that condenser spark discharges are especially rich in the spectral lines of their metallic sparking

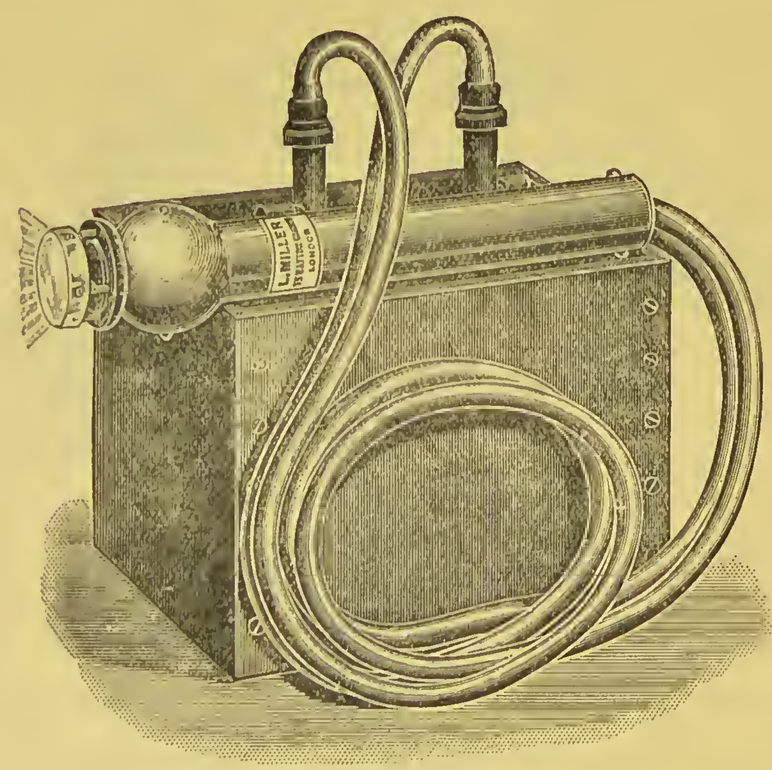


Fig. 152.—The condenser spark lamp.

points. It consists of a cylindrical metallic holder enclosing a pair of iron rods between which a stream of condenser discharges is maintained. The end of the tube is closed by a window of quartz and this is pressed upon the part to be treated. The current is obtained from Leyden jars, or from an oil-immersed condenser which is fed with current at a high potential obtained from a large Rhumkorff coil, or from a high potential transformer connected to alternating electric light mains. As a source of ultra violet rays this instrument is unequalled. In the treatment of lupus it has proved itself of

genuine utility, and the instrument offers many advantages over the cumbrous carbon arc lamps, not least of which is the very small proportion of troublesome heat rays which it gives out.

339. **The use of fluorescent compounds.**—In order to augment the effect of treatment by light rays it has been suggested that some fluorescent substance should be given internally, or should be applied externally to the affected part. Dr. Morton, of New York, has advocated the use of quinine and of other fluorescent alkaloids, such as æsculin, in the treatment of malignant disease, and Tappeiner, of Munich, and others, have experimented with eosin and other fluorescent aniline dyes.

Professor von Tappeiner has stated that certain fluorescent substances which in darkness were scarcely toxic acquired in sunlight or diffuse daylight the power of destroying infusoria and cells and of neutralizing toxins and enzymes. Even weak solutions of the substances in question exhibited this photodynamic action. He had examined eosin, chinolin-red, harmalin, acridin, and fluorescin, and found that their photodynamic action was in inverse ratio to the degree of fluorescence. By the action of the above substances ricin, for instance, lost not only its general toxic quality but also its power to agglutinate erythrocytes, diphtheria toxin was rendered absolutely inert, and tetanus toxin was considerably weakened. By experiments on animals inoculated with diphtheria toxin it was found that the fluorescent compounds had also a certain therapeutic effect. Injections of eosin had a beneficial effect in rodent ulcer, lupus, and chancre. Although the photodynamic action increased as the fluorescence diminished, it nevertheless came to an end completely when the fluorescence disappeared.

Dr. Seifert (Würzburg) confirmed the above statements as to the therapeutic results obtained by eosin in lupus and mycosis.

340. **The electro-magnet.**—In certain cases this instrument is very valuable for the removal of fragments of iron or steel from the various parts of the body, especially from the eye. If the particle of iron be very small, or if it be fixed at all firmly in the tissues a magnet is not likely to remove it. But if the piece of metal be larger, and if it be lying loose, as, for example, in the interior of the eye, it may be withdrawn most successfully by a magnet introduced through a small incision.

One form of the instrument adapted for small battery power is

shown in fig. 153, and another much larger apparatus, known as

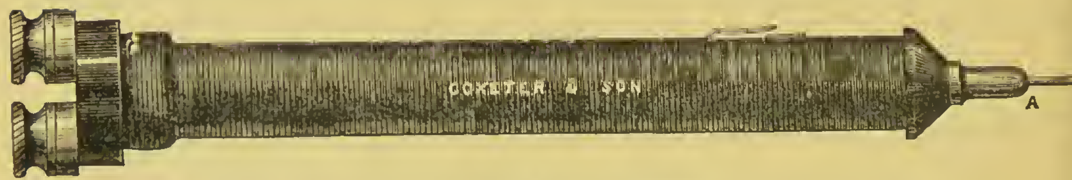


FIG. 153.—Electro-magnet.

Haab's electro-magnet in fig. 154. This instrument is wound

FIG. 154.—Haab's electro-magnet.

for 100 or 200 volts for direct connection to electric lighting

mains. It is fitted with several circuits and switches and with a resistance frame for regulating the strength of its magnetic field. Several interchangeable pole pieces of different shapes and sizes are generally supplied, and the most suitable one for each case can be screwed on as required. It is sometimes useful to excite the magnet by closing the current circuit after it has been placed in position near to the piece of iron. If this is done the sudden magnetization tends to jerk the piece of metal away from its bed. The vitreous humour will yield and allow the piece of iron to come forward to the magnet. In firmer tissues it is not always possible to extract it by an electro-magnet, for naturally it cannot hold the particle as firmly as it would be held by any kind of forceps.

A large number of communications on the electro-magnet in surgery will be found in the medical journals.*

* See "The Electro-Magnet in Ophthalmic Surgery," by Mr. Simon Snell, and *Brit. Med. Journal*, Nov., 1883.

CHAPTER XVII.

THE RÖNTGEN RAYS.*

The Crookes' tube. Radioscopy. Radiography. Localisation of foreign bodies. X ray dermatitis. Radiotherapy. Rodent ulcer. Malignant disease. Lupus. Eczema.

341. **Kathode rays and X rays.**—The discovery of the X rays by Röntgen at the end of the year 1895 followed upon the work of Lenard, who, experimenting with the highly exhausted tubes known as Crookes' tubes, had found that he was able to obtain manifestations outside the tube. Before this time the attention of observers had been so fixed upon the phenomena taking place within the tube that effects outside the tube had not been noticed. Lenard, following up a hint given to him by Hertz, and working with tubes provided with an aluminium window, found that a Crookes' tube, when excited, emitted radiations to which he gave the name of kathode rays, which could be recognised in the open air outside and around the tube, and that these radiations had the power of exciting phosphorescence and fluorescence† in suitable bodies, and of acting upon sensitive photographic plates in the same way as light; and, in particular, that this action on photographic plates could take place through the sides of a cardboard box, which had little effect in stopping the radiations. Following

* In this chapter it is not possible to give more than a general outline of the methods employed in X ray work. Special monographs on the subject are now necessary by reason of the very great development which the subject has undergone. The following books may be consulted:—"The X rays in Medical and Surgical Work," by Francis Williams; Macmillan, London and New York, 1903. "The Röntgen Rays in Therapeutics and Diagnosis," by W. Pusey and E. Caldwell; W. B. Saunders, Philadelphia and London, 1903. "The Röntgen Rays in Medical Work," by David Walsh; Baillière, Tindall & Cox, London. "Elements of General Radiotherapy," by L. Freund; Rebman, London, 1904. "Traité de radiologie médicale," by Ch. Bouchard, with many collaborators; Steinheil, Paris, 1904. This work has 1,100 pages.

† The word fluorescence is used to signify a phosphorescence which does not last for any appreciable time after the withdrawal of the exciting stimulus.

upon this Röntgen showed that a Crookes' tube also gave out other rays which penetrated opaque bodies in proportion to their density, and could be made to throw shadows on a photographic plate, which when developed would give an image showing any inequalities of density in the object photographed. Their penetrating power was much greater than that of Lenard's kathode rays. It was a natural step from this to make a photograph of the hand showing the bones: and upon this, again, the very important development of X ray work in surgical and medical practice has been erected. Röntgen also showed that by the use of screens painted over with fluorescent materials it was possible to obtain visible images of bodies by means of X rays. Professor Röntgen's work was much more than this, for he distinguished between Lenard's "kathode rays" and his own or X rays and indeed this distinguished physicist worked out the whole of his subject so thoroughly as to leave but little for subsequent investigators to discover.

A vacuum tube in which the exhaustion of the air has been pushed to an excessively high degree is called a Crookes' tube, because Sir William Crookes first pointed out the meaning of the phenomena which can be observed in such an apparatus. It differs from an ordinary vacuum tube in the appearances which it presents when electrically excited. Whereas an ordinary vacuum tube appears filled with glowing gas during the discharge of electricity through it, the properly exhausted Crookes' tube shows none of that appearance; but instead of this a peculiar fluorescence of the walls of the tube, previously hardly apparent, becomes a prominent feature. The vacuum in a Crookes' tube is about one-millionth of the pressure of the atmosphere, and the fluorescence in such a tube is caused by a bombardment of its walls by negatively charged gaseous particles propelled with enormous velocity from the kathode. The object of the high exhaustion is to diminish the amount of residual gas in the tube to such a degree that the particles set in motion at the kathode shall be free to move in straight lines, without obstruction or retardation through collisions with one another. Thus the higher the vacuum the more freely can they travel. In tubes of low vacuum their movement would be obstructed and arrested before they could travel the required distance. It was shown by Crookes that these molecules are propelled in straight lines from the surface or surfaces of the

kathode, and continue to travel in straight lines until they strike an obstacle, such as the walls of the tube itself, or of any body intentionally enclosed in the body of the tube and in the path of their movements.

Crookes' extremely interesting Presidential Address to the Institution of Electrical Engineers, 1891, should be read by all who wish to trace the history of the work with which he led up to the discovery of X rays.*

The particles moving from the kathode are not fragments of the metallic kathode itself, although this view was advanced by certain observers. Crookes himself showed that this was not the case, and proved that they were gaseous particles derived from the residual gas in the vacuum tube, but he considered that they were in a peculiar "ultra gaseous" condition, and he further alludes to the conditions within the tube as a "fourth state of matter," or matter in radiation.† It is now accepted that the particles concerned in the kathode stream are much smaller than atoms, probably about one-thousandth part of the mass of an atom, and the word electron is now used to signify them. They move with an enormous velocity, comparable with that of the speed of light, and this stream of electrons constitutes the kathode rays. In virtue of their nature as electrically charged and moving particles they are acted upon by a magnetic pole, and can be deflected from their course by its means. It will be seen later that X rays are not influenced by a magnet, and this is evidence that X rays are not composed of electrically charged particles.

When the kathode rays strike any solid object this motion is arrested, and it is their sudden impact or arrest of motion which gives rise to the X rays. The X rays are radiations or disturbances in the ether, and thus differ fundamentally from the stream of negatively charged electrons which constitutes the kathode rays. In some of the forms of tube devised by Crookes for showing his effects the kathode rays strike upon the glass wall of the vacuum tube, or upon bodies enclosed within it, and produce a fluorescence, and at the point where they strike they

* See *Journal of the Institution of Electrical Engineers*, 1891, or *The Electrician*, January, 1891.

† "The molecules . . . . at these high exhaustions, under electric stress have become exalted into an ultra gaseous state, in which very decided properties, previously masked, come into play."

generate X rays. In the earliest X ray tubes also the kathode stream was caused to fall upon the wall of the bulb, but these tubes were not able to cast sharply defined shadows because the rays were emitted from large and irregular surfaces.

X rays differ from the ethereal radiations which constitute light in consisting in irregular solitary impulses, whereas light radiations are even undulations following one another in a regular sequence.

342. **Properties of X rays.**—In common with ultra violet light X rays have the properties of discharging an electrified body by ionising the air surrounding it. With X rays discharge takes place whether the body be positively or negatively electrified. X rays also excite fluorescence in certain substances, especially in the platinocyanides of barium and potassium, in some uranium compounds, as uranium fluoride and in calcium tungstate. They act upon sensitive salts of silver, producing the same action as that of light, and they penetrate opaque bodies, although these are not all equally transparent. In a general way it may be said that bodies are opaque to X rays in proportion to the atomic weights of the elements composing them, thus aluminium with an atomic weight of 27 is more transparent than sulphur whose atomic weight is 32, and platinum and lead whose atomic weights are very much greater are also very much more opaque to X rays than the former elements.

Under different conditions of the X ray tube X rays of different qualities are emitted, and this is made use of in practical work to provide a choice in the exact degree of penetration best suited for different branches of X ray work.

Correctly speaking an X ray tube in action is emitting X rays of different qualities or penetrating powers, and the output of a tube can be filtered, as it were, by causing it to pass through a layer of some substance which is capable of absorbing the less penetrating rays, while allowing the more penetrating rays to pass.

343. **Production of X rays.**—The essential parts for the production of X rays are two in number—a Crookes' tube, suitably modified, which will be spoken of as an X ray tube, and an electrical apparatus capable of supplying currents at the electromotive force necessary to excite the tube to action.

The instruments in use for obtaining the high electromotive

forces needed to excite an X ray tube are the induction coil, the statical machine, the high potential transformer, and the Tesla coil. Of these the induction coil is the most generally useful, and most practical X ray work is performed by means of coils.

For the construction of X ray coils see Chapter III., § 68, *et seq.*; and for the uses of electric light mains in the operation of these coils, see §§ 96 and 103.

The proper size for good X ray work is a twelve-inch coil. Fair work may be done with a six-inch coil, and X ray photographs can be taken with a coil which is only capable of giving a two-inch spark. But in practical work it is found that the more powerful the coil the better will be the results, and the shorter will be the necessary period of the exposure. A larger coil also permits of greater latitude in the choice of a tube, for a coil of low power may not be able to excite tubes of high resistance, for use in taking photographs of the thicker parts of the body by means of the more penetrating rays.

With a twelve-inch coil the tubes also last longer than with smaller coils. The increase of resistance of the tube or its "hardness" which comes from use comes more slowly with the larger coils. It appears as though the electrical stresses set up at these extra high electromotive forces are sufficient to break down the resistance of almost any tube.

The statical machine also has advantages, but it has the one great disadvantage of not being portable except in the smaller sizes, and these have not yet shown themselves equal to the coil. It is therefore not possible to use it for cases requiring the application of X rays except in the consulting room.

One of the special advantages of the statical machine consists in its simplicity. Whereas a coil requires accumulators to drive it—and the recharging of these accumulators may be a matter of great difficulty in remote or country places—the statical machine is a self-contained electrical apparatus capable of generating the necessary electromotive force by itself whenever its handle is turned. It also gives a steady radiation with X ray tubes, which is much less tiring to the eye with screen work than the flickering light given by the interrupted discharges of the induction coil. In fact, for screen work, the statical machine is admirable. For photography it is slower than the induction coil, though perhaps it gives finer focus in the pictures, and wherever an apparatus is required which need

not be transported to the bedside of the patient, the statical machine has much to recommend it.

The discharges of the statical machine are uni-directional and the X ray pictures which it gives are clearer in consequence. Some loss of sharpness necessarily follows the use of induction coils by reason of the impulses in the wrong direction which form part of the ordinary induction coil discharge.

344. **High potential transformers for X ray work.**—The Tesla coil affords a convenient means of obtaining currents of high potential, wherever alternating electric light mains can be tapped, but it is not very suitable for exciting X ray tubes. It is bad because it gives an alternating current, whereas the current of the induction coil is more nearly uni-directional. This, however, is not the only objection to it. The real objection is that its discharges are high frequency discharges, and high frequency discharges behave in a very peculiar manner inside a vacuum tube. Strange to say, it is very difficult to confine them to the leading-in wire so as to deliver them where wanted at the surface of the kathode. They have a strong tendency to escape into the vacuum tube from the stem or support of the electrodes in order to pass from the metallic conductor into the gaseous one. If the stems be protected by a glass tube, as is usual, they will quickly puncture this, and opposite the point at which they so puncture the glass stem, they quickly heat the wall of the tube and cause it to crack. On this account the use of the Tesla coil is rendered so costly and troublesome that it is now almost totally neglected in X ray work.

Other forms of high potential transformer have been used, particularly by Villard, who contrived a method of arresting the semi-phases which were in the wrong direction, in order to obtain an uni-directional discharge through the tubes. This valve tube will be referred to later (§ 349). More recently a revolving commutator driven by a synchronizing motor has been devised by Dr. Koch for rectifying the impulses of an alternating current and utilising a transformer for the excitation of X ray tubes. This instrument has not yet come into extended use, but it is probable that it may offer certain advantages as a means of producing X rays, particularly in places supplied by alternating current mains. Its great advantage is the abolition of impulses in the wrong direction which injure the tubes, and

tend to blur the photographic images. With large coils, especially when they are worked from sources of current at high pressures, these back impulses acquire an importance which is not nearly so evident when induction coils are driven from a few cells of a battery or accumulator.

345. **The working of coils for X ray work.**—The gradual extension of X ray work in hospitals and among private practitioners has led to much enquiry as to the best way of working coils from electric light mains. In dealing with such a question much depends upon the circumstances under which any given coil is to be used. It may be as well to commence by saying that accumulators or electric light mains are absolutely necessary for X ray work. Primary cells need not therefore be considered.

When an electric lighting supply is not available a small gas engine and dynamo (§ 57) is to be preferred. The transportation of accumulators to a source of electricity at a distance, for recharging, is out of the question for hospital work. The dynamo plant once laid down will remain a serviceable source of electricity, and with a set of accumulators it would suffice to run the engine once or twice a week to keep the battery in a fully charged state.

The most convenient pressure of supply in such a case would be forty volts. At this pressure there is much less strain upon the interrupting devices, and these therefore work better and last longer. A pressure of forty volts moreover permits of rapid interruptions and a steady light upon the fluorescent screen. Mackenzie Davidson's break or a form of turbine break (§ 70) are the best, the motors of these breaks to be wound for use at the same voltage (40 volts) as that at which the coil is to be operated.

The next case to be considered is that of a place where direct current mains can be used. § 96 deals with this case, and it need only be added that for ease of working and low first cost, the method of charging accumulators from the mains through a lamp resistance, and the subsequent employment of these with the mechanical break will meet all requirements.

It is an advantage in some ways to be content with low pressures to excite X ray coils. When excited at 20, 30, or 40 volts there is less trouble from the inverse discharges or "discharges at make" of the coil, while at pressures of 100

or 200 volts these inverse currents become important, blurring the photographs and wearing out the tubes.

When the lighting current supply is alternating the simplest arrangement is one with the electrolytic rectifier (§ 101) using this to charge accumulators. Other methods are described in §§ 100 and 103. If the high potential transformer referred to in the preceding section should prove satisfactory in working, it is probable that this may in time entirely replace the use of the Rhumkorff coil for X ray work on alternating circuits.

346. **X ray tubes.**—The greatest improvement in the design of special Crookes' tubes for X ray work was effected by Mr. Jackson, of King's College, London, who contrived a tube with a piece of platinum fixed in such a position as to receive the concentrated bombardment from the kathode. The X rays in this form of tube are emitted from a small area of the surface of

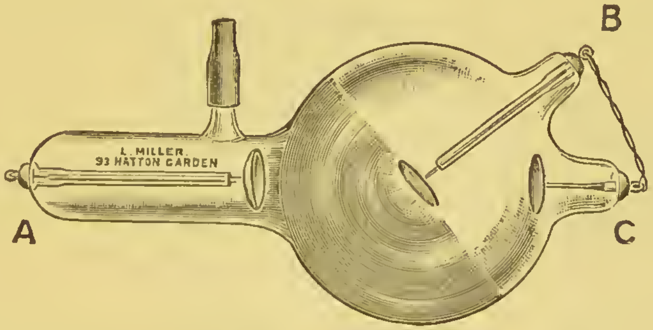


FIG. 155.—X ray tube. A. Kathode. B. Anti-kathode or target. C. Anode or third terminal.

the platinum instead of from a large portion of the glass wall of the tube. The kathode usually takes the form of a cup-shaped disc of aluminium ; and the platinum target or anti-kathode devised by Mr. Jackson is placed nearly at the focus of the kathode. Owing to the cup-shape of the kathode, the bombardment converges to a point at or near the surface of the anti-kathode.

Figure 155 shows the Jackson tube in the form in which it is now most widely used. In it one may see the cup-shaped kathode, the obliquely placed target or anti-kathode of platinum, and a third terminal which is usually connected to the anti-kathode by a wire outside the tube, and which acts as a regulator, making the behaviour of the tube more constant. The probable action of the third pole is to serve as a means of

relieving the molecules of their electrical charges, thus setting them free to return to the kathode, whence they are again repelled. During use an X ray tube becomes gradually more and more difficult to excite; and many tubes have eventually to be discarded, owing to their vacuum having become so high as to resist the full power of the coil used for exciting them. Tubes with a third pole increase in resistance much more slowly. The actual degree of vacuum which is best in a tube will depend upon the electromotive force which is available for exciting it. Thus a tube which is too high for a small coil will serve admirably for another of greater power. There are, therefore, fairly wide limits of vacuum within which X ray effects can be produced. The higher the vacuum in the tube, the stronger is the electromotive force necessary to work it, but the better is the quality of the X ray radiance emitted. Or rather, one may say, the greater is the power of penetration of the X ray radiance emitted. At the high vacuum the velocity of the bombardment is greater by reason of the higher electromotive force needed to excite the tube, and the X rays generated are more sudden and more penetrative. Sir Oliver Lodge, in his lectures to medical practitioners on physics applied to medicine,* writes as follows:—"The rays given off are then specially penetrative, the reason is that the kathode rays come flying off without obstruction, reach a maximum speed, and are more suddenly stopped. The higher the vacuum the thinner the pulse of the X rays, and the more penetrating they are." The words "soft" and "hard" are commonly used to designate tubes of lower and of higher resistance respectively. Thus we may say that a tube which is soft when new will gradually become harder and harder with use, and will therefore become more suitable for photographing the thicker parts of the body and less suitable for photographing the thin ones. If too "hard" its rays may have too high a penetration, and will then traverse bones almost as freely as soft tissues and will give a photograph in which the contrasts between the bones and the soft tissues are insufficiently marked.

Dr. Mackenzie Davidson has proposed to use a piece of solid osmium to receive the bombardment from the kathode. Platinum is too soft a metal to stand the full effects of a sustained bombardment concentrated upon one point on its sur-

* *Arch. of Röntgen Ray*, 1904.

face; and on this account in ordinary X ray tubes the platinum anti-kathode is intentionally placed at a little distance beyond the actual focus of the bombardment. When osmium is used, its hardness and infusibility make it possible to place it in the exact focus of the discharge, and the X rays emitted by such a tube are therefore emitted from a smaller radiant point, and throw sharper images than the ordinary tubes. Unfortunately the osmium anti-kathodes have proved troublesome to work with and have not come into general use. Solid osmium is also almost impossible to purchase. Nickel anti-kathodes are now often employed.

The size of X ray tubes has progressively increased since their introduction. It is found that a large tube ages less rapidly than a small one, and also varies less in its condition during the period of an X ray application.

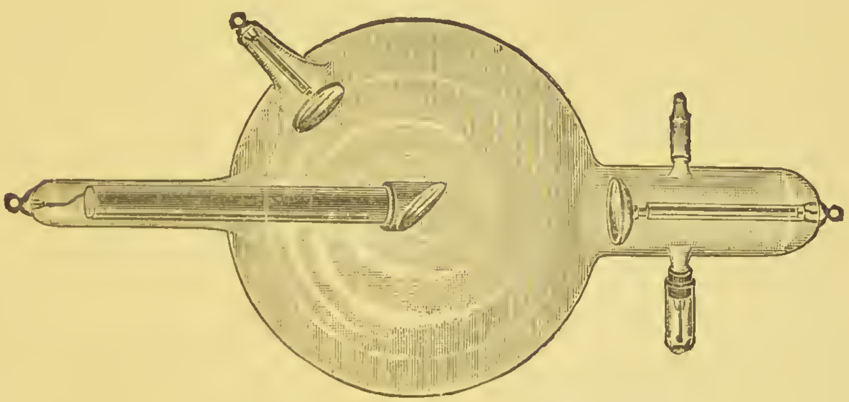


FIG. 156.—Tube for heavy discharges, with osmo-regulator of Chabaud.

When high speed interruptors are used the discharges follow each other in such rapid succession that the tubes are likely to become overheated. The anti-kathode may become red hot, or may actually be fused, and the tube ruined. Even with moderate work the anti-kathode often becomes heated to redness during an exposure, and its vacuum may be inconveniently changed thereby. To obviate these difficulties tubes have been made with special arrangements. Water-cooled anti-kathodes (see fig. 159), or anti-kathodes backed by an extra mass of metal (fig. 156) are employed. With the electrolytic breaks of Wehnelt and Caldwell these tubes are almost indispensable.

347. **Equivalent sparking distance.**—The resistance of a tube is usually specified in terms of the length of air gap which

offers an equal resistance, when arranged as an alternative path in parallel to the tube. If the points of the discharger of the coil are gradually brought together while the coil is in action supplying an X ray tube, a stage is reached when the discharge of the coil sparks across through the air between the discharging points instead of passing through the tube. With different tubes the distance apart of the discharging points at which this takes place varies considerably, consequently this method of measuring the "alternative path" provides a means of estimating the resistance of a tube, or more correctly, the magnitude of the electromotive force necessary to excite the tube.

If the sliding rods of the discharger are suitably graduated in inches or centimetres, the measurement of the alternative path is made easier, and the contrivance has been called a spintermetre or spark measurer.

348. **Comparison of tubes.**—The method just described enables one to compare the resistances of X ray tubes, and so to form an idea as to the quality of the radiation they will emit, but it is far from being sufficient to act as a guide as to the amount of X rays emitted at any particular moment. The two factors, quantity of radiation and quality of radiation, are quite distinct, and must not be confounded together.

Another way of estimating the quality of the X rays, or their penetrating power, consists in a comparison of the relative opacities of two or more bodies of different densities with the rays under examination. This is done in the roughest way when the image of the hand is viewed on the fluorescent screen, and the blackness of the shadow cast by the bones is compared with that thrown by the soft parts. When the bones appear relatively dark the rays of the tube are said to have a low degree of penetration, and when they appear light, and hardly darker than the soft tissues the tube is said to be giving rays of high penetration.

L. Benoist has invented an instrument, the radiochromometre, for observing the relative opacities of dissimilar bodies, using for comparison silver and aluminium. Professor Röntgen had previously designed a similar apparatus for comparing aluminum with platinum. Benoist's instrument consists of a disc of aluminium so cut away as to form a series of twelve sectors arranged in steps of different thickness, ranging from 1 millimetre to 12 around a centre. The aluminium of the centre of

the disc is removed and the opening is occupied by a circular piece of sheet silver ·11 of a millimetre in thickness. The image of the whole combination is viewed by a fluorescent screen, and the amount of fluorescent effect transmitted through the silver is compared with that coming through different thicknesses of aluminium. Some of these latter appear brighter and some darker than the silver, the penetration of the rays is deduced from observing which of the numbered thicknesses of aluminium is most closely comparable to the silver. The more highly penetrating the rays are the more do they penetrate the aluminium. With a tube of high penetration the ninth or tenth thickness of aluminium throws a shadow comparable with that of the silver. With a low tube the thinner layers numbered two or three do so.

Röntgen further showed that the interposition of a substance such as thin glass between the tube and the scale could alter the ratio shown in the instrument, by its effect in stopping the rays of low penetration.

The chromo-radiometer of Holtzknecht is an instrument which serves to measure the active rays emitted by a focus tube just in the manner in which a photometer measures the actinic light for photographic purposes. Dr. Holtzknecht uses a chemical substance, the colour of which grows gradually darker under the influence of the rays; a disc covered with this material is exposed simultaneously with the patient, and the change in colour of the chemical has to be compared from time to time with a standard scale. The amount of effect can thus be accurately estimated by following the instructions sent out with the instrument. The material can be bleached and used again several times.

Holtzknecht's apparatus thus measures the quantity of X radiation, while Benoist's indicates its quality.

Other instruments in the nature of fluorescent screens backed by variable thicknesses of lead foil can be used in the same way.

These devices are now being superseded by more satisfactory methods. It has been found that it is possible to construct a galvanometer which will carry the currents of the Rhumkorff coil and withstand the tendency to sparking between its windings. This can therefore be used to measure the actual current in milliampères which is traversing the X ray tube, and the output of X rays is found to be proportionate to the actual current in

circuit. This procedure is quite different to that of the measurement of the ampères and volts of the primary circuit used for exciting the induction coil, which has had a certain vogue in the past, although useless as a guide to the output of the X ray tube set in action thereby.

In the future the proper application of X rays will require a milliamperemeter in circuit in order to determine the quantity of X rays in use. The resistance of the tube, or its "hardness," can be simultaneously determined by the alternative spark method, and thus it will be possible to specify the current in milliampères used in an application and the resistance of the tube in terms of the length of the parallel spark, and these, coupled with a measurement of the distance from the tube to the plate and of the time of exposure will provide all the necessary data for an exact estimation of the conditions of the experiment.

349. **Rectifiers of high potential currents.**—In order to measure the effective current through an X ray tube with any correctness it becomes necessary to prevent the passage through the tube of any impulses in the wrong direction. This is necessary not because of any difficulty in the measurement of currents which alternate in direction, but because it would be a misleading operation to measure currents of which some unknown proportion was ineffective for the production of X rays.

In the case of the static machine the current is unidirectional and can be measured direct, and in the case of the transformer of Koch (§ 344) the same result follows owing to the means adopted for rectifying the current. With induction coils the same result can be obtained with fair success by a device of Villard's known as a "*soupape*" or valve tube (fig. 157). Villard* showed in 1899 that a vacuum tube with its internal metallic poles or armatures arranged in a certain way offered a great resistance to the passage of current in one direction through it, while permitting of an easy flow in the other. The valve tubes of Villard are made with a wide central space into which one terminal projects freely in the form of a corkscrew, while the other terminal is of small area and is enclosed in a much narrowed part of the tube. Under these conditions the tube conducts easily when the first terminal is kathode, but has an extremely high resistance for currents in the other direction.

* *Arch. d'élect. méd.*, May, 1899.

One or more of these tubes arranged in series with an X ray tube in such a way that the kathode or large armature is directly connected to the anode of the X ray tube, will act very well in arresting the impulses in the wrong direction, and will permit measurements of current to be made. See *Arch. d'élect. médicale*, July 25, 1904, for a new transformer apparatus of Gaiffe's with valve tubes and milliamperemeter for X ray work.

The resistance of the valve tube should be maintained at such a stage as to show a violet luminosity and no green fluorescence.

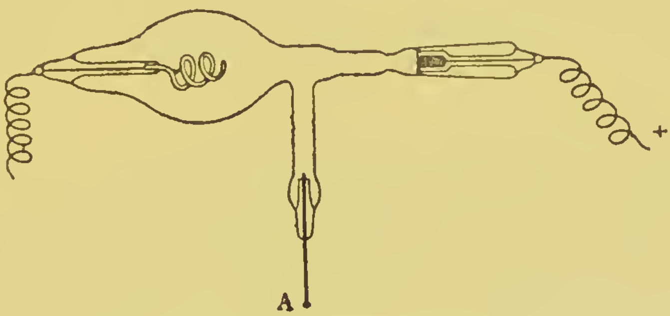


FIG. 157.—Valve tube of Villard with osmo-regulator at A.

350. **Regulation of vacuum.**—The inconveniences arising from the gradual ageing of X ray tubes when in use have led to the introduction of many contrivances for lowering the vacuum if it becomes too high. Some of these devices depend upon the inclusion in a side tube of a chemical compound, such as caustic potash, which gives off vapour when warmed. When such a tube becomes too high its vacuum can be lowered by the warmth of a spirit lamp applied cautiously to the part containing the chemical compound. Another method of temporarily lowering a tube is to warm it all over with a spirit lamp flame or before a fire. If a spirit lamp is used while the tube is in action the operator should use one with a long non-conducting handle to escape shocks or puncture of the tube from sparking, and to keep his hands away from risk of X ray burns.

Prolonged baking of a tube in an oven at a high temperature will often lower an X ray tube more or less permanently.

A very ingenious method of reducing the vacuum depends upon the power possessed by platinum of becoming permeable to gases when heated. A thin walled tubular wire of platinum closed at its outer end is sealed into a side branch of the

X ray tube. It projects inwardly and outwardly for a distance of about an inch. If the outwardly projecting part is held in a spirit lamp flame gases from the flame are absorbed by the metal, and emitted again so as to enter the tube. This is known as the osmo-regulator of Chabaud. It is shown in figs. 156 and 157.

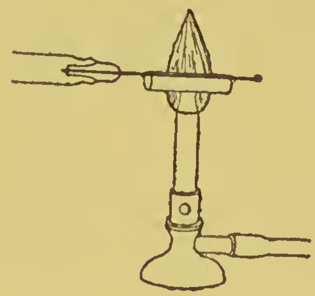


FIG. 158.—Method of increasing vacuum, with Chabaud's regulator.

It is said that by a modification of this device the opposite effect can be produced, and the vacuum within the tube can be raised if necessary. To effect this the wire is enclosed in a loose sleeve of platinum open at both ends. When this sleeve

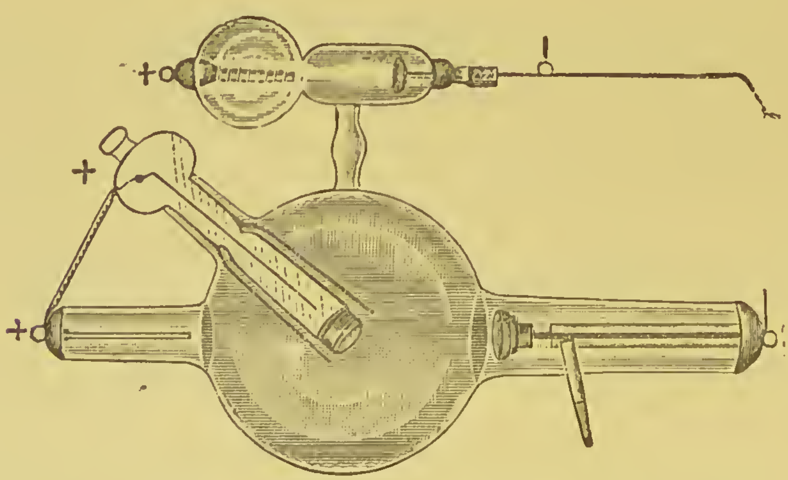


FIG. 159.—Self-regulating tube with water-cooled anti-kathode.

is held in the flame it protects the wire from the gases of the flame and is traversed by a flow of atmospheric air. Under these conditions there is a tendency for gas to diffuse outwards from the inside of the tube. This is a slower and less certain process than that previously described (see fig. 158).

Another tube-regulation method is the use of an accessory

side bulb to the tube with terminals between which sparks can be passed at will. The special terminals of the side tube are constructed of some material which will emit gas when heated by the passage of sparks, and the gas so disengaged enters the main body of the tube and lowers the vacuum. The figure shows an arrangement of this sort, of a very convenient kind. The long wire is hinged and can be so placed that a spark may pass to it whenever the vacuum becomes too high, and in this way the tube is made self-regulating (fig. 159).

351. **Couch for X ray work.**—Many forms of couch have been devised for X ray work. In the best designs the arrangements for carrying the tube form part of the combination.

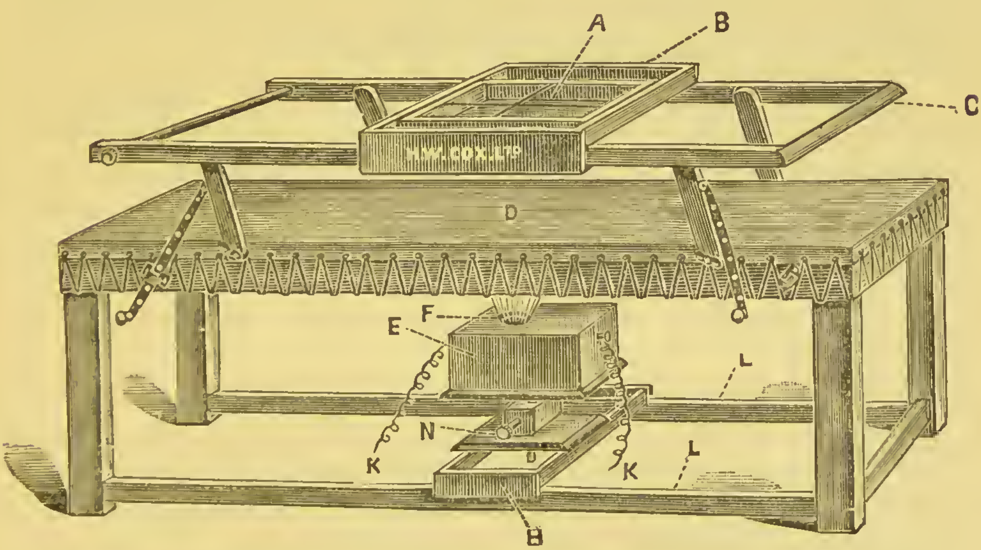


FIG. 160.—Hall-Edwards' couch for X ray work. A. B. Carrier for plate or screen, on hinged frame C. E. F. Tube box, sliding on carriers H and N.

For most screen examinations except perhaps in simple inspections of the upper limb it is a convenience to have the patient in a recumbent position and to examine him from above. The tube holder should slide on guides L L beneath the couch so as to be moveable by a mechanical arrangement without interruption of the connecting wires K K, and the part of the couch upon which the patient lies, D, is to be made of cotton or other material transparent tc X rays. With a couch of this kind any part of the body can be inspected at will, and neither the patient nor the operator need adopt the uncomfortable attitudes which are required for the examination of a patient in a standing or sitting posture.

For stereoscopic work, and for localisation purposes, special arrangements have been designed by Mackenzie Davidson, in order to simplify the changing of plates necessary to obtain a pair of pictures. Davidson's scheme permits of the substitution of the first plate by the second with ease and certainty, and will be referred to in a later paragraph (§ 358).

For photographic work the general arrangement is to have the tube above the patient and the plate beneath. This is more likely to ensure immobility during exposure. Certain operators, however, use the same arrangement as that already described for screen examinations, and are able to obtain sharp results with the plate simply laid upon the patient's upper surface, while the tube is fixed as before below the couch. A convenient indicator which shows when the tube is vertically beneath the part to be photographed is fitted to some of these couches.

352. **Tube stands.**—The clamps by which X ray tubes are held are of many patterns. They should be made of wood, and should be sufficiently massive and well balanced to prevent vibration of the tube from being set up by slight disturbances in its neighbourhood. Figure 161 shows a good form of stand and tube holder. Other forms of clamp to screw to the wall are made, but are not so generally useful as those which stand upon their own foot.

The best position of the tube in relation to the plate is that in which the long axis of the tube is parallel to the plane of the limb to be photographed. Nothing is gained by tilting the tube so as to bring the anti-kathode surface parallel to the limb or the photographic plate. On the other hand nothing is lost by such an inclination of the tube.

The cone of rays emitted by a tube in action is one of such a large angle that it is usually easy to include the whole area submitted to the rays in its more central parts. Definition and illumination are naturally better in the centre of the cone than at its extreme edges.

353. **Radioscopy. The fluorescent screen.**—When the apparatus has been connected up and works satisfactorily the performance of the tube may be tested by means of the fluorescent screen. When set in action the phosphorescence of the tube is the indication which shows whether the direction of the discharge through the tube is correct. When the kathode of the tube is properly attached to the negative pole of the coil, the

phosphorescence will occupy one hemisphere only of the tube, the hemisphere which fronts the face of the anti-kathode which is turned towards the kathode. This half of the tube (fig. 155) then appears evenly illuminated by a green phosphorescence. If

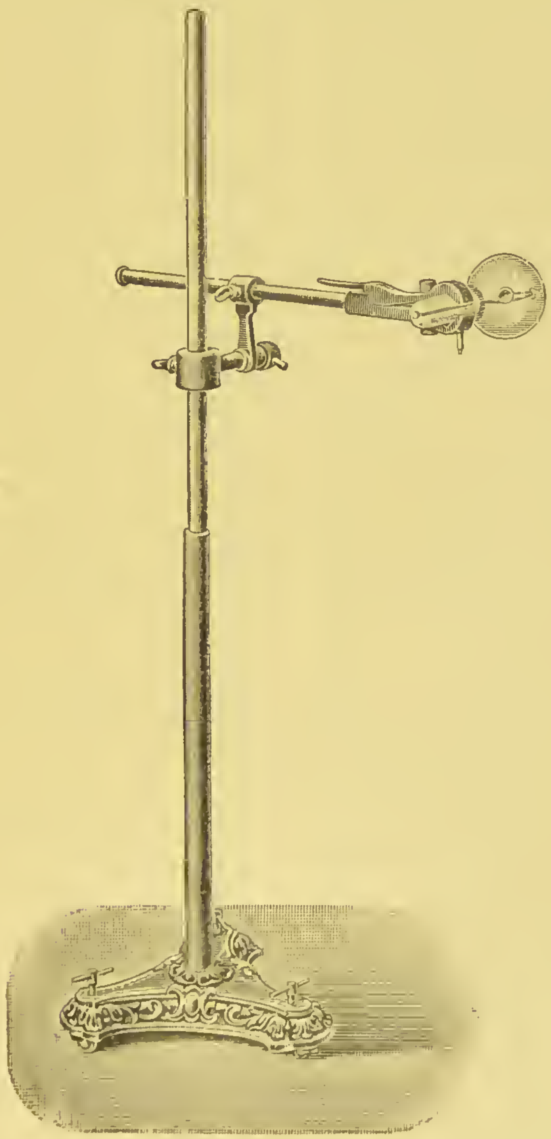


FIG. 161.—Tube stand.

the connections are wrong, the phosphorescence inside the tube is not thus sharply confined to its proper hemisphere, but is irregular and ill-defined on all parts of the tube. If the room is dark, a fluorescent screen held in front of the anti-kathode will

shine brightly, and the hand placed between it and the tube will throw a shadow on the screen in which the bones are quite easy to perceive. A common size for the fluorescent screen is one of ten inches by eight inches. Larger or smaller ones may also be used. But the small screen is often to be preferred to a larger one, because with a screen much larger than the part under scrutiny the eye may be troubled by the fluorescence of the outlying portions.

Various substances have been tried in the manufacture of screens, but the material which has finally asserted its superiority is the platino-cyanide of barium. This fluoresces with a greenish-yellow light and has no phosphorescent after-effect. A little work in a dark room with a screen can be made extremely instructive. In this way one can learn how easy it is to produce distorted impressions when the object viewed is not in a plane parallel with the surface of the screen. And from this one recognises how important it is in taking X ray photographs to arrange the careful adjustment of the tube, the patient, and the photographic plate, in their relations to each other.

The use of the operator's own hand to estimate the working of the tubes may lead to chronic X ray dermatitis if indulged in too frequently.

The fluoroscope is a screen arranged inside a dark box, with apertures for the eyes. It is designed for use in daylight, but is of slight practical value in medical work.

354. **X ray photographs.**—In medical work X ray photographs are taken by means of photographic plates enclosed in light-tight envelopes of paper, or in light-tight plate holders. The plate is usually enclosed in a yellow envelope, which again is enclosed in a black envelope. By this means the action of ordinary light upon the plate is prevented, but the passage of X rays to the plate is not interfered with. The plate enclosed in this way is laid upon a table or other support, and the limb is placed upon it. The tube is then adjusted at a distance of a foot or eighteen inches above the limb, and the coil is set in action. The hand or limb must be kept quite still during the exposure, which may last from a few seconds up to many minutes, according to the efficiency of the apparatus and the density and thickness of the part to be photographed. Care must also be taken to avoid vibration or movement of the tube. As soon as the exposure is concluded, the coil is turned off, and

the plate, still enclosed in its envelopes, is removed to a dark room where its development is carried out in the ordinary way, as in simple photography. The approximate times of exposure when using a twelve inch coil may be set down somewhat as follows:—For the hand and wrist, fifteen seconds; forearm, upper arm and elbow, one minute; shoulder and thorax, three to five minutes; knee and thigh the same; pelvis and abdomen up to six minutes. By the use of rapid interruptors these times can be considerably reduced. With smaller coils longer exposures will be necessary. But it must not be thought that a long exposure with a small coil will give equivalent results to those obtained from a short exposure with a large coil. The larger the coil the quicker may be the exposure, but in addition the sharper would be the picture.

Sometimes one is annoyed by finding on development a general blurring and blackening of the photographic plate which otherwise shows little or no detail. This is a trouble especially met with in the photography of thick parts of the body, with coils of poor power and long exposures. In photographing these subjects it is necessary to make use of large coils, and to shorten the exposure to the minimum which will serve to give an image of the part desired. The most difficult parts to photograph clearly are the vertebræ, the kidneys (for renal stone), the pelvis and hip joints, and long practice is needed in gauging the performance of the tube, and in adjusting the time of exposure to the bulk of the subject before uniform success can be expected. When a tube has been found to have reached the degree of vacuum which just suits these parts with the coil used, it is well to treasure such a tube, and to keep it only for these special subjects, using some other not so good for the easier parts, such as the hands and feet, the forearms and legs. The tube should be fixed so that the rays can fall perpendicularly from it upon the limb and the plate. Obliquity in the position of either the plate or the limb is likely to give that distortion which has been referred to in a preceding paragraph. A little study of these distortions as seen upon a phosphorescent screen held in various oblique positions is the best method of learning what effects these distortions produce, and also the best way to avoid them.

Envelopes of the proper kind can be obtained from the makers of photographic materials. Various kinds of photographic plates have been specially recommended from time to time, but there

does not seem to be any conspicuous difference between one kind and another. It is better to choose one kind of plate and adhere to it, because in this way the peculiarities of the plate during development are the more quickly learned. In putting the plate into the envelopes before exposure a little care is needed in order that the film or sensitive side may face in the right direction. The plan is to put in the plate with its film side away from the flap or opening, and then to put the yellow envelope into the black envelope, with the plain sides in apposition. The side with the flap or opening of the envelope is then the side of the glass or non-sensitive side; the other is the side of the film which must face the X rays. As with choice of plate, so with choice of developers; it is best to make use of those with which one is best acquainted. A very simple and convenient developer is rodinal. It has the advantages of easy preparation, of effective action, and it does not stain the fingers. As with X ray work the exposures are seldom very far removed from what may be called the minimum normal exposure, a simple developer of maximum strength can usually be employed without the risk of spoiling the plate in the process of developing, and whenever the exposure and the development are both carried out by the same person it is found that a time is soon reached when one may very closely assimilate time of exposure and strength of developer so as to give the best results. The question of skilful development belongs rather to photography than to medical electricity, and in many cases the plates are sent for development to professional photographers.

An over-exposed plate may be known by a fulness of detail in the whole plate with a general blackness of the whole subject if development is fully carried out, while an under exposed plate shows very great contrasts with absence of detail in the parts least blackened. An over exposed plate which has been developed for too short a time will be thin and lacking in density all over, although it may show details of structure in all parts of the subject. When many photographs have to be done, the time lost during prolonged exposures may become a serious item. But in ordinary private practice, where it is not likely that many plates require to be done at one and the same time, it is better to give a full time exposure to the plate, in order to get all the detail which is possible. The question of the proper time to give to the different parts of the body is one which only

practice can settle, for it depends upon the size of the coil, the energy with which it is driven, the quality of the tube that is being used for it, and the distance between the tube and the photographic plate. The nearer the tube is to the plate, the shorter need the exposure be. But, on the other hand, distortion is more evident in plates exposed with the tube very close than it is in plates exposed with a tube which is distant. For fine work, then, one will be content to have the tube at a distance of eighteen inches or two feet from the object, and to give a slightly longer exposure.

355. **Secondary radiations.**—The general blurring or blackening of the photographic plate which has been referred to is due to several causes. In the first place there is a production of secondary X rays by the incidence of the rays upon the surroundings of the plate. The air in the neighbourhood of a tube in action is thereby rendered a source of X rays; and these though of low intensity are able to fog a plate if the exposure is at all prolonged.

Again, the back discharges of the coil pass through the X ray tube and excite an irregular production of X rays which tend to blur the photographic image.

Various means can be adopted to counteract these bad effects. The valve tube of Villard (§ 349) can be used to arrest the impulses which tend to traverse the tube in the wrong direction. The secondary radiations can be counteracted to a great extent by placing a thin layer of aluminium in front of the plate to stop the radiations of low penetration while permitting the others to pass through. The use of a plate of lead or of thick plate glass as a backing to the plate also sharpens the photographic image by absorbing the rays which have penetrated the plate before they can give rise to secondary radiations behind it.

The use of diaphragms or short wide lead tubes between the tube and the subject have also been recommended, with the intention of cutting off all but the central portion of the cone of rays emitted by the tube.

356. **Applications in diseases of the chest.**—The detection and localisation of foreign bodies in the tissues is one of the most obvious of the applications of X ray work in surgery. The examination of fractures, dislocations, and other changes in connection with the bony skeleton is even more important.

And perhaps more important still in the future may be the detection of changes in the soft tissues. The shadows cast upon photographic plates by X rays depend upon the different densities of the objects photographed. Thus, whereas in a photograph of a limb the contrast is between bone and the soft tissues, the detail being visible in the bone and the detail in the soft tissues being almost non-existent, yet in cases like the thorax, where the more dense heart is surrounded by the less dense lung, it becomes possible to obtain valuable photographs of the heart and of the lungs respectively. Changes in the size and shape of the heart, or of the aorta (aneurysm) can therefore be detected. In the lungs any changes tending to consolidation of the natural spongy tissue can be detected for the same reason. Tumours, consolidations—pneumonic and phthisical—and effusions into the pleura are all easily recognised in good X ray photographs of those parts. Cavities can also be seen. Its application to the study of chest diseases is perhaps one of the most promising of all the applications of X ray work in medical practice. Valuable work in that direction has been done in the electrical department of St. Bartholomew's Hospital by Dr. Hugh Walsham.* He was the pioneer of this section of X ray work and his results have been confirmed by later writers.† This field of diagnosis is likely to progress considerably when it has been studied further. In the photographs of the chest, as in those of the limbs, the combination of two pictures by means of the stereoscope is often of great value in enabling one to form an estimate of the actual position, and depth from the surface, of any tubercular consolidation or tubercular cavity; for a cavity can be revealed by X rays just as well as a consolidation, although for the opposite reason, namely, that whereas a consolidation is denser than the normal lung, a cavity is less dense.

It is unnecessary to dwell upon the value of the X ray photographs as permanent records of past conditions in a slowly progressive disease like phthisis.

* "Present Day Skiagraphy," *Clinical Journal*, 1901, vol. 18 (figures). "On the Diagnosis of Thoracic and Cardiac Aneurysms by the Röntgen Rays," *Edinburgh Medical Journal*, i., 1901 (figures).

† J. T. Halls Dally "On the Use of the Röntgen Rays in the Diagnosis of Pulmonary Disease," *Lancet*, June 27, 1903.

A. Stanley Green, "The Value of the Röntgen Rays in the Diagnosis of Pulmonary Tuberculosis," *Arch. of the Röntgen Ray*, viii., 144.

357. **The localisation of foreign bodies.**—A difficulty which early shows itself in the localisation of foreign bodies by means of X ray photographs is the difficulty of determining the plane in the limb in which the foreign body is placed. Various plans for localisation have been devised. In this country the stand and localiser of Mr. Mackenzie Davidson are in almost universal use.

The principle upon which Mr. Mackenzie Davidson's localiser depends is the measurement of the displacement of the image of the foreign body on the photographic plate which is produced by a measured displacement in the position of the tube. Two

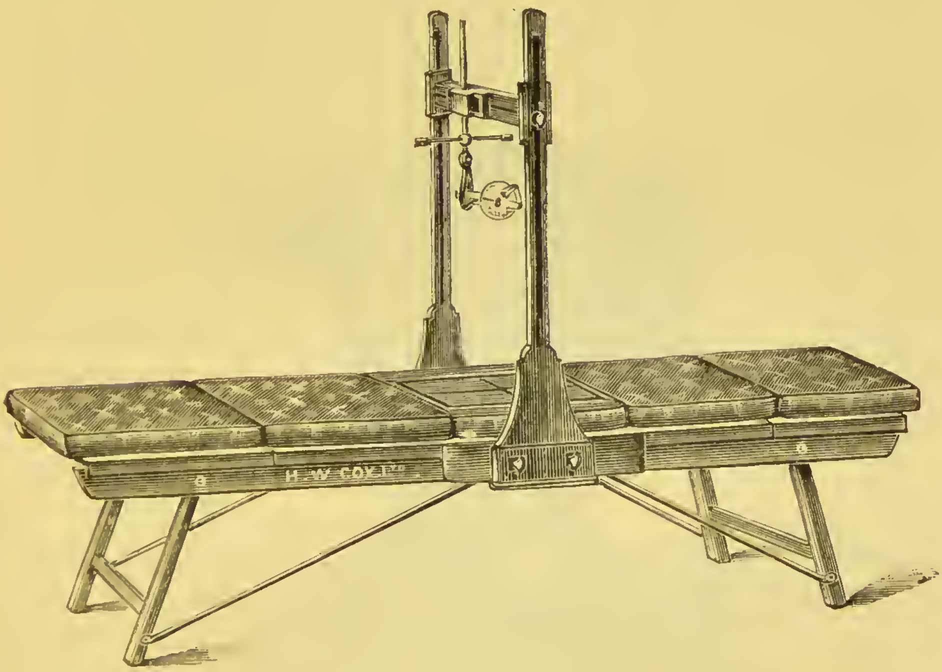


Fig. 162.—Davidson's localising couch with tube holder and changing box.

exposures are made upon the same plate with the limb perfectly still, a known displacement being given to the tube before the second exposure. This operation is easy with the forms of tube stand provided for the purpose (fig. 162). Then, the distance of the tube from the plate being known, and the amount of the lateral displacement of the tube being known, a diagram can be constructed taking in these two factors and the measured displacement of the image of the body on the photographic plate; and from this, by a calculation, the distance of the foreign body from the surface of the photographic plate can be deduced. In prac-

tice the calculations are very much simplified by the use of the localising apparatus in which two threads represent the axis of the rays from the two positions of the tube. These start from the two points and are brought down to the two images of the foreign body which are seen upon the photographic negative. The point where the two threads cross in the air above the negative is the point at which the foreign body is situated.

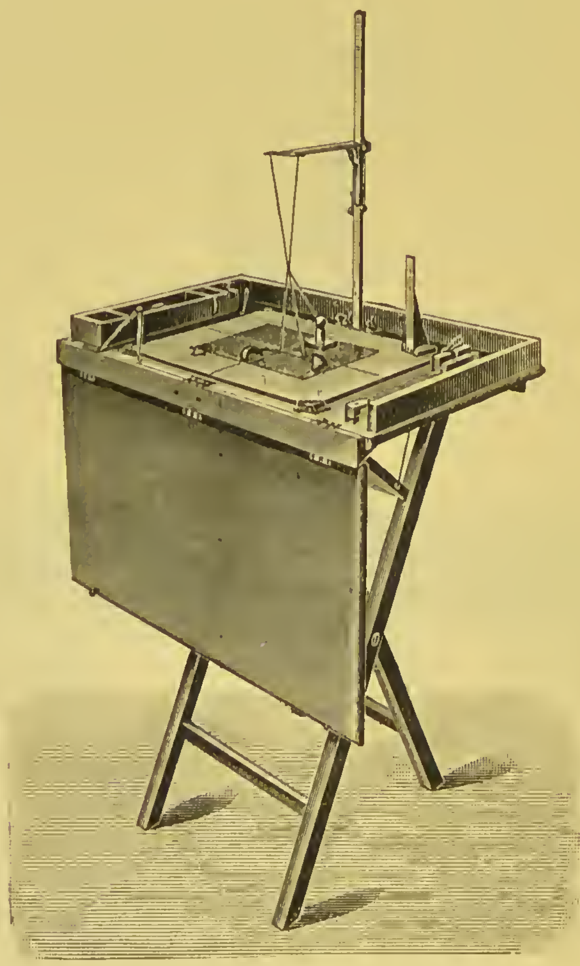


FIG. 163.—Davidson localiser.

That, indeed, is the only point at which it can be, in order to throw the two images which it has thrown. By means of simple measuring scales supplied with the apparatus, the height or the depth of the body from the surface with which the plate was in contact is readily calculated by measuring the position of the point at which the threads cross in the air. Its distance to right

or left from a given point in the photograph can also be measured quite easily.

A fine wire dipped in an aniline dye is tied round the packet containing the sensitive plate; when the limb is placed in position and the photographs are taken, the image of the wire is recorded in the radiograph and the dye leaves an imprint upon the patient's body. After development, the plate is placed beneath the localiser stand and the two indicators, which are connected with the scale by means of silk threads, are set precisely to the corresponding spot in each of the images—the cord from the right-hand side going to the image on the left, and that from the left to the image on the right. The point of intersection of the two cords gives the precise depth of the foreign body in the tissue. Fig. 163 shows the arrangement.

Its position laterally will be known by reference to the image of the cross wire, and as an imprint of this will be upon the patient's body, the surgeon can make an incision with absolute certainty of finding the substance sought for.

In this country the Davidson localiser is used almost exclusively and it answers its purpose quite satisfactorily. In France a method designed by Marie, of Toulouse, is very clever and simple. It makes use of a stereoscope through which the images (negatives or prints) are viewed. A description of this apparatus and its mode of use will be found in certain French works.*

For the localisation of foreign bodies in the eye and orbit Mackenzie Davidson has designed a special form of head rest† which serves to support the patient's head and the plate, and also holds the tube at a fixed distance. The importance of determining the exact position of a foreign body, as for instance a pellet of shot, in the orbit may be very great because the presence of a shot in the globe of the eye might require the removal of the eyeball, whereas a shot in the soft tissues behind the globe might permit the eye to be preserved.

358. **Stereoscopic radiography.**—In very many cases the position of the foreign body can be estimated with considerable accuracy by the method of taking two photographs and viewing them in a stereoscope. For this the two photographs are taken

* Castex, "Electricité médicale," Paris, 1903. Bouchard, "Traité de radiologie médicale," Paris, 1904.

† *Transactions of the Ophthalmological Society*, 1898.

not on the same plate, but on two separate plates, but the tube is displaced for the second exposure, just as in the process just described. The negatives may be viewed direct if a means for illuminating them by transmitted light can be arranged. From the two negatives two prints are prepared, and these are viewed by means of a reflecting stereoscope. The binocular image thus obtained has a most remarkable effect in reconstructing to the observer's eye the entire part of the body in which the foreign body lies; and it appears to stand out with all its roundness and thickness, and the foreign body also can be seen as it lies in the depth of the tissue in such a way as to give a very real picture of its actual position and depth from the surface.

In order to obtain two plates which shall be in correct register,* some device in the nature of a changing box is used. This is secured by having a table made with calf skin covering a space cut out of the top (fig. 162). This is stout enough to support a considerable weight, and at the same time is thin and transparent to the X rays. The photographic plate enclosed in a black paper cover in the usual way, is placed beneath the skin and supported against it by some suitable arrangement of clips or screws. The horizontal bar above the couch carries the tube holder, and allows it to be displaced to either side, for a measured distance.

In the figure a cross wire is shown stretched over the surface of the calf skin, but a better position for this wire is to place it close over one edge of the plate and parallel to it. It then leaves a white line at the end of each negative and enables the photographs to be mounted correctly in register. The part of the patient to be skiagraphed is placed over the calf skin. Two photographs can easily be taken in this way on different plates without disturbing the position of the patient.

The Wheatstone form of reflecting stereoscope should be used.

"Two plane mirrors, about four inches square, are so fixed on a vertical support that their backs form an angle of 90° with each other. When the observer puts his face close to the edge where the mirrors meet, so that this edge lies vertically between his eyes, it follows that his right eye can see only what is reflected in the right mirror, while his left eye can only see what

* From the paper by J. Mackenzie Davidson in the *Brit. Med. Journal*, Jan. 1, 1898.

is reflected in the left mirror. Now, if the two skiagraphs, taken as already described, are placed so that the right eye image is opposite the right mirror, and the left image opposite the left mirror, each eye will recognise its own picture, and they will combine, as usual, and give rise to a single image in perfect relief (fig. 164).

"There are several devices for supporting the skiagraphs, and also for simultaneously making them approach or recede from the mirrors. The simplest of all arrangements is to have two mirrors mounted on an upright block of wood, which can be placed upon a table, while the skiagraphs can be supported by any simple means in the proper position. A form of revolving Wheatstone stereoscope can be contrived in the following way A four-sided box, which can be revolved on a vertical rod, is

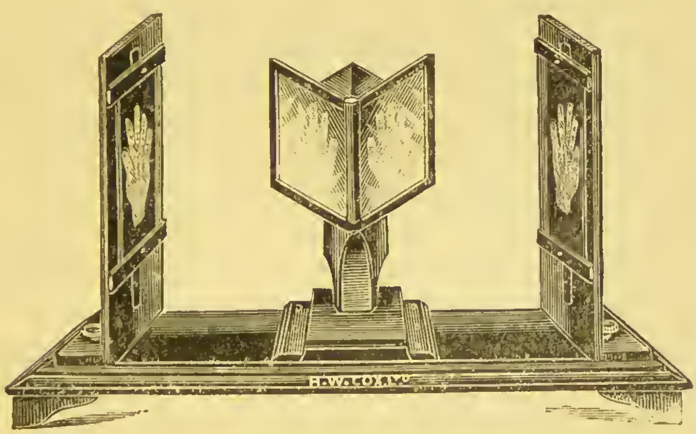


FIG. 164.—Wheatstone's stereoscope.

placed opposite each mirror. Upon each of its four sides one of a pair of stereoscopic skiagraphs is placed. The corresponding pictures are similarly placed on the other box. In this way the boxes can be rotated, and two corresponding skiagraphs brought simultaneously in correct position opposite the mirrors. This prevents the necessity of adjusting each pair separately, and saves time in demonstrations. The block supporting the mirrors is attached to a small base with bevelled edges, which slides in a broad groove, and enables the observer to slide the mirrors towards or away from his eyes. In this way he can adjust the mirrors to the position which enables him to combine the pictures most comfortably. Each revolving box is fixed by its vertical support to its sliding board. This allows the distance of the skiagraph from the mirrors to be altered at will.

"The Wheatstone stereoscope is peculiarly adapted for X ray photographs—first, because, as everyone knows, a print from an X ray negative is reversed; for example, if a skiagraph of a right hand be taken, when printed it appears to be a left hand. Now, if such a print be viewed in a Wheatstone stereoscope, it is reflected in one of the mirrors, and is thus reversed to its original position by the reflection. Therefore, if opposite the right mirror is placed the print from the negative produced when the Crookes' tube was displaced to the right side, and opposite the left mirror the print from the negative taken when the tube was displaced to the left, the observer will then see the parts in correct stereoscopic relief, as if he had been looking at them with his eyes placed so that the right eye was at the point occupied by the anode when displaced to the right, and the left eye at the point occupied by the anode when the tube was displaced to the left. If the skiagraphs be viewed under the same angle as they were taken, the stereoscopic picture would show the parts of the true or actual size, and the exaggerated distortion of the single X ray photograph is overcome. The importance of such a result to a surgeon is great.

"There is no limit to the size of the pictures which can be seen in a Wheatstone stereoscope. The largest size the writer has as yet taken stereoscopically is 12 by 15 inches.

"If the right picture be placed opposite to the left mirror, and the left picture opposite the right mirror, a stereoscopic picture will be seen as before, only reversed. For example, in one case a hand will appear as seen from the dorsal aspect; if the prints are transposed, it will appear as a hand seen from the palmar aspect. The same transposition can be effected by turning each print upside down.

"The negatives, when wet, can be seen in a stereoscope if they are held in proper position by upright frames, and each illuminated by a strong light diffused through ground glass or white paper, but the effect is not so good as viewing prints.

"If it be desired to reproduce the radiograms as illustrations in a book or periodical, they can be reduced and mounted alongside of each other.

"By practice it is not difficult to acquire the power of combining stereoscopic pictures without an instrument of any kind. There are two ways of doing this:—

"1. By looking beyond the photograph, so that each eye sees the picture opposite it.

"2. The most easily acquired and most important for X ray work, as it enables skiagraphs of any size to be seen at once, consists in crossing the visual axes. This may be accomplished as follows: The photographs or radiographs are placed correctly in front of the observer; he then holds up his finger in the middle line between his eyes and the skiagraphs, and while looking at the top of his finger he will observe double images of each radiograph; by a little perseverance he will learn to make two images of them in the centre combine, and he will then have a beautifully clear stereoscopic image apparently in the air. Behind to the right and left will be two images, but these he soon learns to ignore, or he can cut them off by bringing his hands cautiously from the outer side of each eye towards the middle line, stopping the moment the two side images are cut off. It is, of course, convenient in this way to see negatives in stereoscopic relief immediately after development."

359. **Stereoscopic use of the fluorescent screen.**—The principle of the stereoscope can also be applied to screen work.

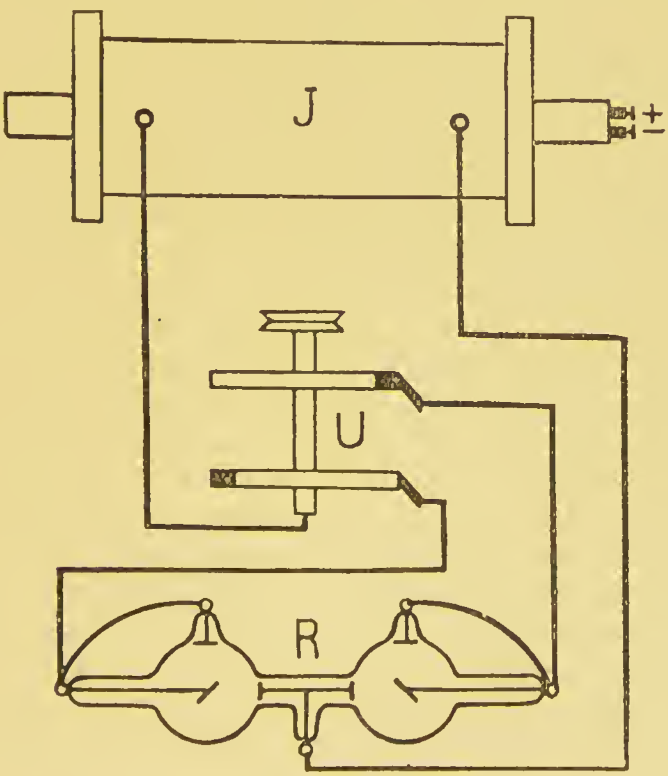


FIG. 165.—Plan of connections for stereoscopic screen work. J. Coil. U. Double commutator. R. Double X ray tube.

Mackenzie Davidson has devised an apparatus for the purpose and it will be found described in the *Archives of the Röntgen Ray*, 1901, vol. v., p. 46.

Two similar X ray tubes are arranged so that the distance between the two anti-kathodes is equal to the distance between the two eyes. As it is difficult to find a pair of tubes which are of similar quality a double tube with two anti-kathodes may be used. By means of a commutator the tubes are illuminated in turn so that they light up alternately at regular short intervals. The observer examines the screen through two openings which are kept opening and closing synchronously with the alternations of light and darkness of the tubes. Thus the right eye only sees the screen illumination caused by one of the X ray tubes, and the left eye only sees the illumination caused by the other. These alternations follow one another with sufficient speed for the eyes to receive continuous impressions, and a stereoscopic effect is produced.

360. **The therapeutic applications of X rays.**—The discovery that exposure to X rays could cause the hair to fall out, and might lead to serious lesions of the skin, led to attempts to employ X rays for purposes of treatment. The removal of hair in cases of hypertrichosis was one of the first things attempted in the way of therapeutics. Soon afterwards it was applied to various chronic forms of skin disease, and in 1900 Sjögren and Stenbock reported the first results in rodent ulcer. The application of X rays to lupus and to malignant diseases of all kinds followed and a vast amount of work has been done in the attempt to cure cancer and sarcoma by this means, so that the current medical literature of the past two or three years has been filled with reports of cases of that kind.

In all the conditions for which X rays are applied the knowledge at our disposal is defective in one important particular, viz., that in all the results which have been obtained by workers in this field of treatment, there is the difficulty of dosage as to quantity and quality of the rays to be employed.

The introduction of galvanometers for measuring the current in the tube will in time permit of more precise work. The quality of the radiations from hard or soft tubes also requires analysis, and this will be easier when the galvanometer removes the difficulties as to quantity.

The points upon which information is needed are the follow-

ing: What should be the resistance of the tube? Should it be operated gently or strongly? Should frequent short exposures be given, or should they be less frequent and of longer duration? At what intervals should they be given, and at what distance of the tube from the surface of the skin?

In general, exposures are given with the tube at a distance of eight or ten inches from the skin, the duration most commonly is ten minutes, and repetitions of the treatment are made every other day or twice a week until an erythema shows itself. When this appears, as it may do after eight or ten applications, treatment is suspended until it has disappeared, and is resumed again cautiously. Hard tubes are generally used, having a parallel sparking distance (§ 347) of three or four inches.

In France a different method has been suggested. Oudin proposes to place the tube within one or two inches of the skin, to make exposures on alternate days, the duration of the first being half a minute, of the next one minute, the third one minute and a half and so progressively up to three minutes. Then an interval of a week is allowed to pass without applications, and then if there is no sign of any reaction on the part of the skin the three minute exposures are resumed, and may be raised to five minutes. The appearance of erythema requires the stoppage of exposures until it has disappeared.

361. **X ray dermatitis.**—Exposures to X rays if too long or too frequently repeated set up a dermatitis of a very peculiar kind. Oudin* has given a graphic account of the changes which occur in the acute form of X ray dermatitis, and he describes the course of an X ray "burn" as follows:—

1. At the end of one or two days (or even as late as two or three weeks) from the time of exposure a slight erythema shows itself, and this, instead of disappearing, gradually becomes of a red or livid colour, something like that of a chilblain, until at the end of a lapse of time which may be ten or twenty days or even longer, the erythematous patch becomes the seat of troublesome irritation which becomes worse and worse. Small vesicles or pustules develop on its surface, and these break and leave small ulcerations. Pigmentation of the surrounding skin develops during the same period, and the hairs may fall out.

Ulceration gradually involves the central part of the affected area, and finally a yellowish adherent leathery scab or crust

* "Accidents dus aux rayons X," *Arch. d'élect. médicale*, Sept., 1902.

forms and remains unchanged for many weeks, the part being intensely painful. After the lapse of a longer or shorter time the necrotic patch separates, leaving a raw red surface which heals only very slowly, and may break down again from slight causes. Nothing in the way of dressings seems able to relieve the pain or to accelerate the healing process. It seems to be useful to apply some impermeable dressing, because the contact of air with the sore is quite painful. A year may elapse before the part heals.

The gradual onset after a latent period suggests that the lesion is a tropho-neurotic one, due to the damage sustained by the superficial nerves of the part. Certainly there is partial anæsthesia in and around the affected area which may persist for many months. After healing the part may gradually acquire a nævoid character, and it remains irritable and tender for many years.

Fortunately X ray dermatitis does not always follow this typical course. In the earlier stages the symptoms may recede without the formation of a necrosed area and this is most likely to follow if great care be taken to protect the part from every chance of accidental injury. So soon as the advent of a severe burn is apprehended, the part should be covered with cotton-wool and a bandage. No antiseptic lotions or ointments, no bathing with water nor poulticing should be employed. The writer by proceeding in this way was fortunately able to arrest the progress of a serious burn on the dorsum of his hand. The part was covered with a layer of wool and was sewn up in a glove every day for three weeks. At the end of that time the livid œdematous condition had passed off and the skin separated in one large piece leaving a tender but healed surface beneath. Six years have now elapsed since the time of the burn which was produced as an experiment, and the area is now covered with nævoid patches (telangiectases) and is devoid of hair. Partial anæsthesia is still present, and the final stage of sound scar tissue does not seem even yet to have been reached.

It appears that the effects of a series of X ray exposures of moderate duration are not identical with those produced by one or two prolonged exposures. Most X ray burns of the severe kind just described have followed one or at least few exposures of inordinate length. In X ray treatment it may be necessary to push the exposures to the very verge of causing dermatitis.

In fact dermatitis is often intentionally caused, and it is a strange thing that in experienced hands a sharp dermatitis can be caused without the disastrous sequels described by Oudin. It appears as though a tolerance were gradually established. At the same time no one must fancy that there is any immunity from severe burns in such cases. Many severe burns have been produced during a course of treatment, but generally there is sufficient warning in the shape of harmless erythema to warn an experienced operator.

Scholtz* has reported upon the histological changes caused by X rays upon the skin of pigs. His experiments are given in detail by Caldwell and Pusey,† together with a summary of his results, from which it appears that he found that "X rays influenced especially or exclusively the cellular elements of the skin. These are influenced primarily and undergo a slow degeneration, while the connective tissue, the elastic tissue, the musculature and cartilage are changed only in a slight degree and suffer only secondarily, as a result of the cellular degeneration and the inflammatory reaction consequent to it.

"The degeneration affects the epithelial cells in the highest degree and to a less extent the cells of the glands.

"The degenerative appearances affect the protoplasm and the nuclei.

"As soon as the degeneration has reached a certain point, an inflammatory action appears which manifests itself in a marked dilatation of the vessels, with gathering leucocytes and marked emigration of the blood corpuscles.

"The changes in the vessels are apparently of great importance as affects the further development and slow healing of the ulcerations."

It will be noticed that nothing is here given on the appearances presented by cutaneous nerves, and this is probably an omission of importance. The nerve structures are probably susceptible to injurious effects from X rays, as has also been observed with the similar radiations of radium.

362. **Chronic X ray dermatitis.**—A different form of dermatitis is seen in X ray operators, in persons who are much engaged with X ray apparatus or in the manufacture of X ray tubes. In these persons the skin of the backs of the hands

* *Archives f. Derm. und Syphilographie*, 1902.

† See footnote, p. 444.

gradually becomes chronically inflamed, the skin becomes red and thickened, and develops cracks round the knuckles; the nails become brittle and longitudinally striated and deformed, and the parts are irritable or intensely painful. Eventually ulceration sets in, and when this stage is reached treatment becomes almost ineffectual. Amputation of a finger has been necessary in certain cases, and death from development of carcinoma in the chronically inflamed tissues, with extension into the axilla, has ensued in one case at least. A good photograph of this condition can be seen in the *Archives of the Röntgen Ray*, 1904, vol. viii.

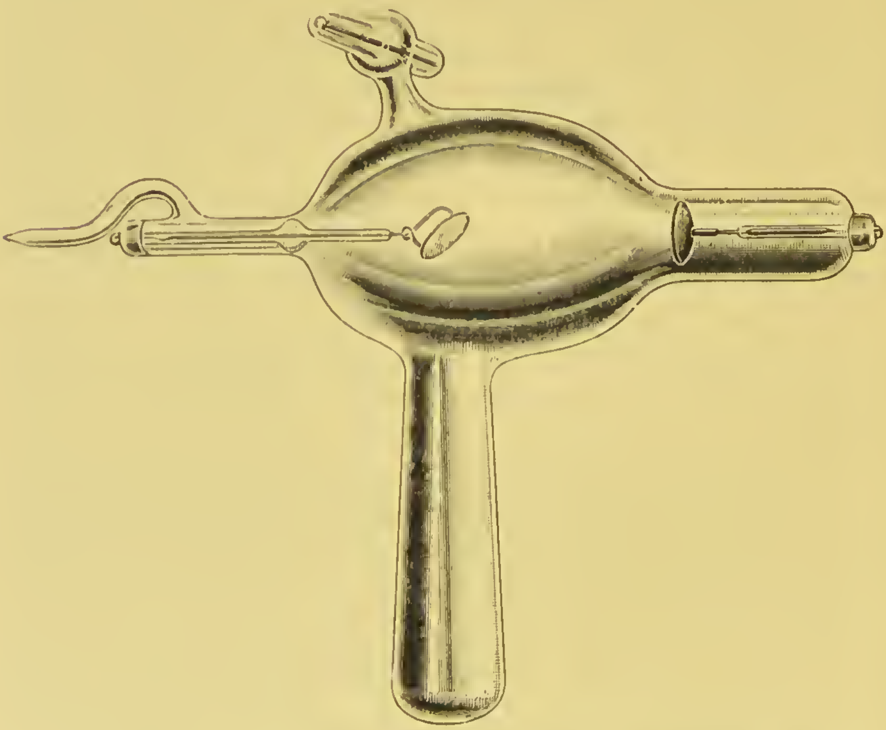


FIG. 166.—Tube of lead glass with window for therapeutic use.

263. **Special tubes for treatment.**—The use of X rays for therapeutic purposes entails frequent applications and the possibility of the production of X ray dermatitis is always present. On this account some plan must be adopted to protect the surrounding parts from needless exposure. Shields of lead foil with apertures cut in them are generally used. Mr. Hall Edwards constructs masks of plaster of Paris to fit the part to be treated, leaving or cutting a window of suitable size. Instrument makers have also manufactured special tubes of lead glass

which is relatively opaque to the rays, with a window of soda glass of small dimensions, in order to limit the radiations to the part which requires treatment (fig. 166).

364. **Tube shields.**—More recently tube shields to fit the tube have been employed, and are now made in many patterns.

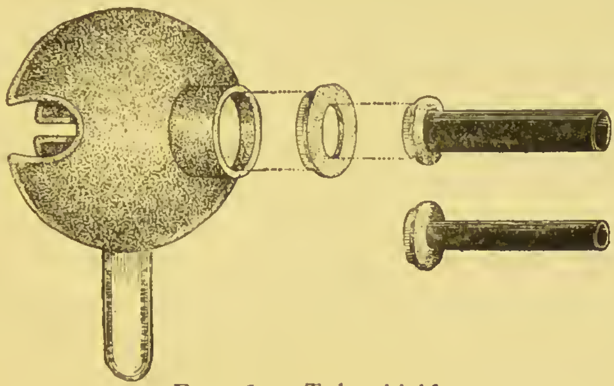


FIG. 167.—Tube shield.

Fig. 167 shows an American pattern known as Friedländer's tube shield which was one of the first of its kind. The opaque shield is of some dense non-conducting material, and is tied to the tube. There is an opening on the side which faces the anti-

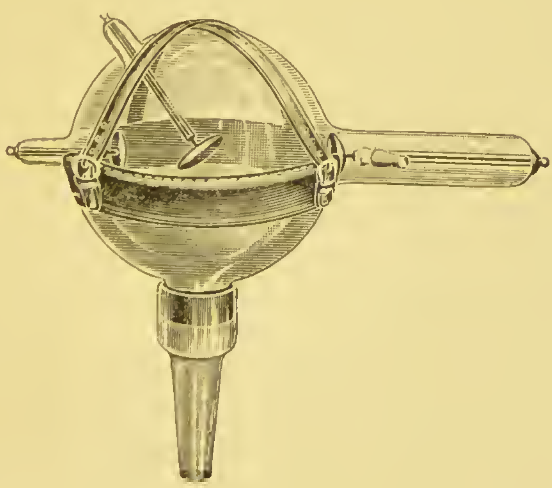


FIG. 168.—Tube shield.

kathode into which tubes of various diameters may be screwed, to suit the needs of a particular case. Fig. 168 shows another contrivance of thick glass, as fixed *in situ* to the X ray tube. It is also provided with sets of side tubes. These shields are of special advantage in the treatment of small rodent ulcers. For

cases of carcinoma their use is less necessary, as they may lead to the protection of infected areas of skin, where the rays are required to exert their effect.

365. **The removal of hair.**—Abroad, the removal of superfluous hairs from the skin by exposure to the X rays has been elaborated by Professors Schiff and Freund of Vienna, and they have succeeded in adjusting the degree of exposure so as to cause a permanent shedding of the hairs without producing destruction of the skin itself. The matter is one requiring great nicety of adjustment, and the technique is dealt with at some length in Freund's book.* In this country the risks of causing permanent damage to the skin have deterred operators from developing this method of removing hairs for cosmetic purposes, although in cases such as sycosis and favus, where the hair must be removed for the cure of disease, or in disfiguring hairy moles, the operation is frequently carried out.

Its risks as a cosmetic process are due to the probability of injurious effects upon the texture or colour of the skin, such as pigmentation, reddening, or the formation of telangiectases, the appearance of which would suffice to defeat the desired object, of improving the personal appearance.

It is comparatively easy to cause hairs to fall out as a result of X ray applications, but it is difficult to do it in such a way as to prevent their return subsequently. The method described at the end of § 360 is perhaps the best procedure for this purpose.

366. **Diseases of the skin.**—X rays have been used with good therapeutic results in a number of cases of acne vulgaris, eczema (chronic), psoriasis and verruca vulgaris, and also in certain parasitic affections of the skin, as favus, sycosis, tinea tonsurans and verruca necrogenica.

X rays are also extensively used for lupus vulgaris, and with less success in lupus erythematosus. In chronic ulceration of syphilitic origin, and in "varicose" ulcers of the leg their effect is often remarkably good. It does not appear that the good effect is due to any bactericidal action of the X rays.

In all the above conditions the *modus operandi* is the same, and consists in exposing the affected part to the radiations of the X ray tube for a longer or shorter time, repeating the process two or three times a week until a good result is obtained. The

* *Vide* supra, p. 444.

majority of workers prefer to use tubes of high resistance and the usual distance of the tube from the patient is one of eight or ten inches.

Sjögren and Sederholm's paper* contains the following details: The results in scrofuloderma appeared to be very successful, although in some it was necessary to produce a considerable degree of reaction.

In ten cases of chronic eczema the result was good in all, and in the greater number the cure was complete. The moisture disappeared at once and the itching ceased. The infiltration of the skin continued to diminish after the treatment had been stopped, until at length it completely disappeared.

Of psoriasis two cases were tried but did not benefit.

In pruritus the result was very favourable in the majority. In a case of hypertrichosis in which acne was present, the treatment proved highly beneficial.

In chronic ulceration in which the cause of the ulceration was uncertain, two cases out of four were cured and one greatly benefitted. The authors add that the only point in common in these cases was that they had resisted other methods.

In four cases of simple warts the effect was excellent. In one of the patients there were upwards of 200 upon one hand. After fifteen applications all the small ones had disappeared, and the larger ones had very much diminished in size. They become smoother and flatter, the height diminishes and they disappear. Large ones require so many sittings that a certain amount of redness may make its appearance.

These reports of the pioneer work in X ray therapeutics are amply confirmed by later work. It is interesting to note that the writers used rather long and strong exposures of ten to fifteen minutes, with the anti-kathode of the tube at a distance ranging between five and seven inches from the skin, and daily repetitions of the exposures. It is not surprising that irritation of the skin was frequently observed, judging by present experience; it is probable that equally good results could be obtained by less frequent applications. Their want of success in psoriasis probably was due to the length or frequency of the exposures.

In the treatment of psoriasis it is advised to keep the expo-

* "Fortschritte auf der Gebrite der Rontgenstrahlen," June, 1901. (Abstract in *Archives of Röntgen Ray*, vi., 18).

sures short, and to avoid the production of any erythematous reaction.

In keloid there have been good results from X ray treatment. Morton* has reported two cases in which the production of severe dermatitis led to the disappearance of keloid. Other observers have also had good results.

367. **Lupus erythematosus.**—This condition is difficult to treat successfully by X rays. Although some cases respond satisfactorily, there are others which remain unchanged or may even seem to grow worse under the treatment. It is also refractory to Finsen light treatment, and to high frequency applications. Temporary amelioration, however, is not uncommon with all these methods.

368. **Lupus vulgaris.**—Much has been written of late years on the subject of the treatment of this disease by physical methods. The famous work of Finsen in the treatment of lupus by concentrated light has excited wide-spread interest, and has stimulated others to attempt the cure of the disease by other physical methods, among which the use of X rays is perhaps the most important. X ray treatment has the advantage that it can be applied over a much larger area at a time than is possible with the Finsen light, and this tends to reduce the time consumed during the treatment, an important consideration in many cases.

Dr. Malcolm Morris and Dr. E. Dore in a valuable paper on the treatment of lupus have compared the effects of X rays with those of the Finsen lamp in this disease.† The following is extracted from their communication :—

"We have treated the majority of our cases of lupus vulgaris with the Finsen light, and the X rays have mainly been employed as a preliminary in cases in which there was extensive ulceration or considerable œdematous thickening. The effect of the rays in bringing about rapid healing of ulcers has in our experience been so marked that we look upon ulceration as a definite indication for their use. Even one application often causes a notable diminution in the discharge from an ulcerating surface. In cases of severe deep ulceration relatively better results have been obtained than in slight superficial sores. This may be accounted for by the fact that in the deep ulcers little of

* *New York Medical Record*, 1903.

† *Brit. Med. Jour.*, June 6, 1903.

the lupus growth is left and the new tissue is more healthy. When the ulceration is superficial healing may occur over a mass of deep-seated lupus, and breaking down is more likely to occur. In a case in which there was severe ulceration of the mucous membranes of the lips and corners of the mouth some improvement followed the continued application of the Finsen light, but permanent healing resulted from a few exposures to the X rays. In another case a small superficial ulcer of the skin of the neck proved refractory to the light treatment, but the application of the X rays produced rapid healing. In this instance, however, the healing was not permanent, and the ulcer had eventually to be excised.

"Rapid absorption of œdema under the influence of the X rays has been observed in several of our cases. In one in which there was marked œdema and protrusion of the upper lip with ulceration of its under surface and of the gums, the lip regained its normal shape and consistence, and the ulceration healed. This case was treated over a year ago and no recurrence has taken place. In the case with ulceration of the angles of the mouth referred to above, the upper lip was also tense and protruding owing to œdema, and the result of treatment with X rays was equally satisfactory. Improvement is also taking place in two cases of extensive œdema of both sides of the face, in one of which there is also œdema of the lobes of the ears.

"When the disease is extensive the X rays may be used as a preliminary to the light treatment. The advantage of this plan is that a large area may be treated at a time. In dealing with extensive surfaces care must be taken not to cause severe dermatitis. We think it doubtful, however, whether permanent results can be obtained without the production of some degree of inflammation.

"When mucous membranes (lips, gums, nostrils, &c.) are the seat of lupus, the X rays are, in our experience, more effectual than the Finsen light. When the inside of the nostrils is involved there is no choice, as the region is inaccessible to the light rays; in all such cases, therefore, we have used the X rays. The immediate results have been very encouraging, obstruction being quickly relieved, discharge ceasing, and ulcers healing after a few applications. It is only after a long course of treatment, however, that results of any degree of permanency can be obtained, and the tendency to relapse is very marked.

We have treated only one case in which the palate was affected; it was extensively scarred from frequent scraping operations, and the X rays produced no beneficial effect.

"Another point on which we wish to lay stress is the palliative use of the X rays. Patients who, either owing to advanced age, ill-health, exigencies of occupation, residence at a distance, or other causes are unable or unwilling to give up much time to treatment may get considerable relief from a short course of X rays. More than once we have succeeded by this means in checking the spread of the disease.

"Although the immediate effects of X ray treatment, especially in cases in which there is extensive ulceration, are so good, our experience so far has been that the initial rapidity of improvement is unfortunately not maintained. Secondary conditions (ulceration, discharge, and œdema) are relieved almost at once; but in respect of eradication of the disease, progress is disappointingly slow, and failure is not infrequent. Opinions differ as to the possibility of entirely destroying the granulomatous tissue. Many cases have been reported in which nodules have remained after long continued treatment. In non-ulcerative lupus the results seem to be less satisfactory as regards complete destruction of the foci of disease."

Dr. Gamlen* has expressed an opinion in favour of low tubes for the treatment of lupus, and this seems to be in accordance with the known fact that low tubes have a greater "burning" effect upon the skin than high tubes. He writes as follows:—

"There are many who place too great reliance in the length of the sitting. In many articles I have read, the period of exposures adopted by the writers was stated to be from ten minutes to an hour every day. This theory has not held good with me. It has always been my object to obtain rapidly a tangible result consistent with safe treatment. Instead of daily exposures I have adopted a system of giving sittings two or three times a week, lasting from three to five minutes. The brevity of the period I attribute to the fact that I use a 14 inch coil, and always obtain an ampèrage of from six to eight, and a forty-volt pressure. When beginning treatment it is impossible to exercise too much care. At this stage I always use a low tube—and then watch the case. The primary object is to

* "Treatment of Lupus by X Rays and ultra violet Rays," *Brit. Med. Jour.*, June 6, 1903.

produce a mild reaction. Perhaps it may be necessary for this purpose to use a still lower tube, and increase the length of the sitting. This is where the faculty of judgment enters into the treatment, and where the individual necessities of the patients must be considered.

"I am firmly convinced that in order to cure, a mild reaction must at the outset be promoted, and then steadily, and even skilfully maintained. The extent of this reaction must be determined slowly by discretion in the regulation of tubes and exposures. Once having found a tube to suit a particular case I obtain thê desired effect by increasing or decreasing the interval and length of sittings, the distance between the patient and the target, and at the same time controlling the current through the coil. In obstinate cases which do not respond readily to treatment I use lower degrees of tubes until I have succeeded in producing a sufficiently severe reaction. Then I suspend the sittings for three or four days or until the result of the exposure is apparent. Upon this I base the course of future treatment. In the majority of cases the dermatitis has become evident within two or three days—somewhat less than the experience of others. The subsequent healing process is tolerably speedy, and the skin, formerly diseased, then assumes a smooth appearance. The severity of the reaction necessary, however, must always depend upon the character of the case and the susceptibility of the patient under treatment. I am greatly in favour of the use of low resisting tubes for superficial surfaces. For this purpose I have compared them with the hard tubes, and find that if judiciously regulated they give more speedy and sure results. Where penetration is necessary, as for deep-seated ulceration, tubes of a hard nature are undoubtedly the most efficacious. This is perhaps the only theory approaching generality which I would be prepared to propound. For instance some tubes, apparently the same in resistance and spark length, produce different effects. The obvious deduction to be drawn is that complete success is to a large extent attributable to a varied supply of tubes, the capabilities of which are well known and recorded."

The late Dr. Barry Blacker pointed out in 1901* that the employment of the X rays in cases of lupus might lead to the cure of patches of that disease which were remote from the parts

* *Brit. Med. Journal*, 1901, ii., p. 850.

specially X rayed. Mr. Hall Edwards has also drawn attention to the same peculiar effect.

369. **Other tubercular conditions.**—Mr. Sydney Stephenson* has recorded a case of tuberculosis of the conjunctiva cured by X rays after 13 exposures.

X rays have also been applied to tubercular diseases of other organs, as for instance to tubercular joint affections, enlarged cervical glands, &c. The results obtained hitherto are conflicting.

In a case, supposed to be tubercular, of angular curvature of the spine in an elderly man, associated with great pain and weakness in the back, and with a lump the size of a walnut on the sacrum, the application of X rays produced a marked effect upon the pain within a week, and this was followed by a gradual disappearance of the tumour on the sacrum and a consolidation of the vertebral curvature. The patient made a complete recovery and the sacral lump had disappeared entirely at the expiry of four months from the commencement of treatment. A year later there had been no return of the trouble.

370. **Trachoma.**—Mr. Mayou† has treated this condition by X ray applications with success. The affected eyelid is everted and a two minutes' exposure is given on four to six successive days. The exposures may be resumed after a few days' rest. After 12 or 15 applications a cure is obtained. Where one eye only has been treated, while the other was shielded from the rays the cure is confined to the eye which had the treatment. D. Walsh‡ has also reported similar results in the same Journal.

371. **Lymphadenoma.**—N. Senn,§ of Chicago, has recorded a case in which X rays seem to have cured a patient suffering from this disease. A man, aged 43, had extensive enlargement of the cervical axillary and inguinal glands and of the spleen. The disease began in the cervical glands a year previously. X rays were applied, one minute each being allowed for each side of the neck, one minute each for front and back of neck, and one minute for each axilla, each groin and the spleen. The

* *Brit. Med. Jour.*, June 6, 1903. With figure.

† "The Uses of X rays in Ophthalmic Surgery," *Archives of the Röntgen Ray*, vol. vii., p. 61, Jan., 1903.

‡ *Ibid.*, p. 63.

§ *New York Medical Journal*, April, 1903.

tube was used at twelve inches distance. A month later the glands were diminished, and the skin over the chest showed erythema. The coil was then operated less strongly, but blisters formed on the chest and the neck, naturally dark, turned dark brown. From April 16 to 23 the exposures had to be confined to the neck, back, and groins, as the chest was the seat of extensive burns. On the 24th all the glands exposed to the rays had nearly disappeared and the hair on the part of the head exposed and in the axillæ and on the pubes had fallen off. The neck was blistered and the nipples were discharging pus. The treatment was suspended. Two weeks later the patient was much improved and was able to return to business. No enlarged glands could be discovered. When seen again on August 1 he felt well but had recently noticed slight enlargement of the cervical and axillary glands. The enlarged glands were treated by exposures of two minutes (for each group), with a current of 28 volts and six ampères, and the swellings prompty disappeared. No relapse has since occurred and the patient is in perfect health.

In a second case, a man, aged 53 years, was seen in the spring of 1902. Ten years before he noticed slight enlargement of the cervical glands and then the tonsils became swollen and painful. A little later the glands in the back of the neck, the axillæ, and the groins were affected. Arsenic, iodides, and cod-liver oil appeared to be useless. To regain health he lived an out-door life in the mountains. After a year the glands were softer but not smaller. The appetite improved and weight was gained. The glands further enlarged until some of the cervical ones reached the size of a hen's egg. On examination the neck was bulging from glandular enlargement and a chain of glands extended from the axillæ to the epitrochlear regions. Some of the trochlear glands had reached the size of a chestnut. The inguinal glands were greatly enlarged. A gland of the size of a hen's egg was felt in the abdomen to the right of the umbilicus. The liver was palpable below the costal arch. The spleen was enlarged but not palpable. The tonsils were enlarged. Examination of the blood showed hæmoglobin 73 per cent. and erythrocytes 3,875,000 and leucocytes 208,000 per cubic millimetre.

The X rays were applied to the affected glands on each side every alternate day, from five to seven minutes being given to

each part. After four or five sittings the patient noticed softening and diminution of the glands. After 15 sittings there were slight dermatitis and symptoms of toxæmia. The patient lost appetite and the anæmia increased. The treatment was suspended. Three weeks later his health was much improved and he had gained 11 pounds in weight. The glands were much diminished and the skin which had been exposed to the rays was pigmented. Examination of the blood showed hæmoglobin 85 per cent. and erythrocytes 4,450,000, and leucocytes 76,000 per cubic millimetre. Exposures of seven minutes were given. After 12 sittings there were slight dermatitis, pigmentation, and loss of hair, and toxic symptoms more pronounced than after the first series of applications. Only one small gland could be felt above the right clavicle and one behind the sterno-mastoid muscle. The axillæ were normal and the inguinal glands had almost disappeared. The leucocytes were 46,500 per cubic millimetre. The spleen extended to within a finger's breadth of the iliac crest. The constitutional disturbance which accompanied the diminution of the glands is ascribed by Dr. Senn to absorption of the products of their degeneration. The patient has written recently that he is in perfect health and that there are no signs of relapse.

The remarkable success of the X ray therapy in these cases certainly indicates its trial in a disease but little amenable to treatment.

In a case of lymphadenoma under my own care no good result followed the repeated application of X rays.

372. **Rodent ulcer.**—All those who have worked at the therapeutics of X rays are agreed that their effect in this disease is satisfactory, and numerous successful cases have been published of late years.

Sequeira* considers that X rays still hold the field as the best therapeutic agent for the treatment of rodent ulcer in those cases in which complete excision of the growth cannot be carried out. He writes as follows:—

"Where the disease is extensive, or where entire removal is impracticable, or again, where the patient shrinks from operation, the X rays give most satisfactory results. Those cases in which there is the greatest destruction often do the best; large ulcers fill up, and there remains only the hard rolled edge to

* *Brit. Med. Journal*, June 6, 1903.

treat. This sometimes proves very resistant, but as a rule will disappear if the treatment is persevered with. In some cases time appears to have been saved by the preliminary destruction of the edge with the cautery before the application of the rays, but this is very rarely required.

"It is very difficult to give any accurate idea as to the time which a given case will have to be subjected to the rays. This is an important consideration with many patients. I have had small ulcers which have entirely healed with from ten to a dozen exposures; but where there are large cavities, and especially where there is a very tough nodular edge, months may be required."

Sequeira is accustomed to apply the rays on alternate days in the slighter cases, and daily in the more extensive ones. He prefers to use tubes which spark at from four to six inches, but finds that the therapeutic value of the tubes is a very variable thing, and one which at present it is impossible to explain. "High" tubes are valuable, as the rays can be applied until there is a definite inflammatory reaction. Actual "burning" is not necessary, and some of the best results have been obtained without any obvious inflammatory reaction at all.

Shenton considers that the production of dermatitis signifies over treatment.

Macintyre has mentioned that he has seen successful results follow treatment by an X ray tube of such high resistance that no X rays could be detected in its neighbourhood on examination with a fluorescent screen.

The quality of tube to employ is by no means settled yet. Although there is this evidence that high tubes are effective, there does not seem to be any to show that low tubes are not as effective, if not more so. The comparative safety which can be obtained by the use of high tubes will naturally predispose to their use in the majority of cases.

Hall Edwards* advises the use of a "hard" tube daily or every other day for ten minutes at a distance varying between eight and four inches. He advises that the exposure should be continued until a well marked erythema surrounds the ulcer, and that treatment should then be stopped, and has found that, as a rule, no further treatment will be necessary, for in the course of a few weeks the healing will have completed. He

* *Treatment*, June, 1903, vol. vii.

considers that the effect of the rays may go on after the suspension of the raying for a period of six weeks or more, granting that the total dosage has been sufficient. He finds that eight, ten, or twelve exposures usually suffice.

It is the case that the effect continues even when it has been insufficient. Thus an elderly patient who was under treatment at St. Bartholomew's was obliged to discontinue his visits after eight times, on account of severe bronchitis. On his return six weeks later he said that improvement had continued for a month of his absence but that matters then become stationary and as he was not quite cured he wished for further treatment. A few more applications sufficed to complete the case.

373. **Carcinoma.**—The treatment of cancer by X rays is still unsatisfactory, although a certain amount of success has been obtained, and the method is still *sub judice.* It is abundantly clear that X rays have a striking influence in promoting the healing of superficial cancerous ulcerations, and in causing the disappearance of the lymphoid nodules which are so commonly seen as the first signs of recurrence around the scar of an amputation of the breast. To illustrate the former point the following case may be described. The case was one of recurrence after removal of the breast, and the patient died of her disease.

The patient had a large ulcer of the right pectoral region, measuring four inches in one diameter and five in the other. Treatment with X rays was commenced on November 14, and an exposure of ten minutes was given four times a week until January 17, with a few omissions. A few days after the treatment was commenced signs of healthy cicatrisation began to appear round the margins of the ulcer. This continued to advance until the healing process had extended inwards from the margin for a distance of fully half an inch all round. The new epithelium was deeply pigmented. The centre of the wound gradually ceased to slough and appeared to be in process of healing all over. But unfortunately, the patient being at a late stage of her illness, secondary deposits in remote parts of the body became very disagreeably evident, the patient suffering a spontaneous fracture of both the femur and the humerus, and the X ray treatment was suspended in view of the hopelessness of the future of the patient. The total number of exposures was seventeen, and it is very important to note that many were made with the ulcerated surface covered by dressing or

bandage. After the suspension of treatment, the process of healing went on quite steadily, until there was a firm and healthy scar covering the whole surface except about one square inch in the centre. This portion was also a healthy healing surface, though not yet covered over by epithelium. Thus nineteen-twentieths of the area of a cancerous ulcer had healed up in three months as a consequence of X ray applications, and the result obviously a most significant one. Although the local effect was so good, there was no influence upon the spread of the disease in the remote parts of the body.

In looking through the published records of X rays in cancer one cannot help feeling surprised to find how few of the alleged successful cases have been so recorded as to carry to those who read them a reasonable conviction of success, and this, too, in spite of the fact that numbers of people are working at this subject, and scores, if not hundreds, of cases have been treated. Half a dozen cases of unmistakeable cure of undoubted cancer, if minutely reported, would be worth more just now than any number of vague statements about partial improvement, favourable effects, and the like. The more one examines the published cases the more disappointed one becomes. In most of them there is some flaw in the evidence. Either the diagnosis is uncertain or the patient is not more than partially relieved at the time of writing, or he has been so unfortunate as to die of some intercurrent disease. It is greatly to be wished that all medical men who have recorded favourable cases will periodically supply further notes of the later progress of their patients. In short, while there is a quantity of evidence to support the contention that X rays act beneficially in malignant disease, the amount of evidence to show that cures have resulted is lamentably meagre. What can be the explanation of this? Here is an agent which very commonly gives relief to some of the symptoms produced by a malignant growth, and yet fails to give as much relief as is really required. Is it because of some defect in our technique, or is it because the cases subjected to X ray treatment are ill chosen, or is it from some inherent defect of the method of a fundamental kind?

Have we yet to discover that the right kind of X ray is only emitted at certain conditions of the tube? Have we to use our tubes differently, or do we fail simply from insufficient perseverance? The nature of the tube, the degree of penetration of the

rays which it gives off, the proximity of tube to the affected part, the production of a reaction or not, are all points on which further knowledge is wanted. Already there is a divergence of opinion as to the need for a dermatitis or not, for while some observers think the good effect is in proportion to the amount of dermatitis, others hold a quite opposite view.*

J. Macintyre,† in discussing the treatment of malignant disease by X ray and other electrical methods sums up his experience as follows:—

My own experience in malignant disease agrees with all I have learned of the subject, and the results may be classified under three headings:—

First, whatever force is used, in a number of cases the results have been a complete failure.

"In the second class, amelioration or alleviation of symptoms only has been obtained. There can be no doubt that many workers have seen great alleviation of pain. Indurations have disappeared, œdema and glands (even at a distance recorded by some) have also been reduced, ulcerated surfaces have been known to take on healthy action and heal after long duration. Proliferating or fungating masses have unquestionably diminished in size, and in some instances the healthy granulations which take their place have been covered with healthy epidermis. General improvement in the patients has been recorded, and in some instances, owing it may be to the restoration of functions, an increase of weight when the patient has previously been wasting has also been seen. In many instances, however, the effects have been temporary only. In my own experience I can say that I have seen some of these results follow the application of high potential currents and also high frequency currents; but I should say for indurations, œdema, glands, and ulcerating neoplasms, X rays have been the most efficacious, and, of course, only in cases of superficial carcinoma, or within accessible cavities.

"In the third class of cases—a smaller one—the lesions have altogether disappeared. It is to such cases that the term cure, if admissible is to be applied. In saying so, I wish it to be

* Lewis Jones. Debate in the sub-section of Electro-therapeutics at the Annual Meeting of the British Medical Association, Swansea, 1903. On the Treatment of Malignant Disease by Electrical Methods.

† *Brit. Med. Journal*, June 6, 1903.

clearly understood that I do not here refer to lupus or scrofuloderma, but to sarcoma and epithelial affections. Even if we regard rodent ulcer as a form of carcinoma, from its clinical history, glandular involvement (or absence of it), slow progress, and rare recurrence, it had better be kept in a class by itself. For therapeutic purposes, whatever be the ultimate outcome of the discussion between different pathologists as to this affection being classed as a carcinoma or not, such an arrangement may save confusion. It is scarcely necessary to point out that when such cases are described as successful cures of carcinoma the layman is not unlikely to interpret the statement as if it meant 'cure of cancer.' What the public mean by cancer usually is the virulent and serious type affecting too often the internal organs. Such views are apt to mislead our patients or their friends, and to raise false hopes in a class of cases for which none of these forces can as yet bring about a cure. That rodent ulcers have been known to heal by one or other of these agencies must now be accepted as a fact, and many cases are recorded from different centres.

"In a smaller number of cases—when we think of the many workers and the number of experiments made, it would be fair to say in a very small number of cases—genuine malignant tumours of the skin, mammæ, and some within accessible cavities have disappeared. Such cases I have myself seen and placed on record. In a still more limited number of cases sarcomatous tumours have also disappeared. What the proportion of satisfactory results may be to the number of failures we cannot now say, and time will be required for the elaboration and collection of statistics ere an authoritative opinion can be ventured upon.

"Lastly, I think it fair to say, however hopeful a view anyone may be inclined to take of the results, one is less impressed with the success which has as yet attended the applications than with the amount of work yet to be done."

Mr. Malcolm Morris in the same number of the *British Medical Journal** in discussing the same matter, expresses the opinion that the X rays are, as far as present experience goes, applicable to the treatment of carcinoma only with strict limitations.

"In cases that are past all surgery a hope, not indeed of cure, but of considerable palliation, is opened up by the use of the

* *Vide* supra.

X rays. The drying and healing effect of the rays on ulcerating surfaces in lupus has already been pointed out. The same holds good, though to a less extent, with regard to the ulcerations of malignant disease. The most marked effect of the rays, however, in cases of cancer, is the relief of pain. In this way life has been made fairly comfortable in many cases where previously it was little better than a prolonged agony. But though the palliative effect is considerable, up to the present nothing in the nature of a cure has been reported.

"Another direction in which the rays find a useful application is in the prevention of recurrence after the disease has been removed by the knife. Superficial nodules can be destroyed as soon as they appear. In the treatment of carcinoma by the rays our experience has been that inflammatory reaction is harmful; this should therefore be carefully avoided. We are inclined to think that weak exposures should be given, especially in acutely inflammatory conditions. The chronic indolent cases appear to do best, while any pre-existent inflammation is likely to be aggravated by the stimulant or irritant effect of the rays.

"With regard to the histological changes resulting from the action of the X rays on cancerous growths there is not much to be said. According to W. F. Brook the epithelial elements of the cancer disappear, but the fibrous tissue remains unchanged, the loosening of the adhesions being due rather to general relaxation from diminution in bulk than to any dissolution of cicatricial tissue. In a case under his care in which the 'lump' after 50 exposures, gradually increased to three-quarters of an hour, was reduced to half its original size, excision was performed, and an examination of the tumour was made by Mr. Shattock, who reported to the Pathological Society of London that no degeneration of any kind or cell lysis had been induced in the carcinomatous epithelium, no phagocytic invasion of the epithelium was in progress, and on every side the growth was in an extending condition. There was nothing in the amount of lymphocytic infiltration in the mast cells and Unna's plasma cells which might not be met with in cases where no treatment had been carried out. The clinical diminution in size of the mass and the loosening of its deep connexions were difficult to explain; possibly they were due to the disappearance of a sub-inflammatory œdema. Mr. Shattock expressed 'profound disappointment' at such a negative finding."

A report of an apparently successful case of cancer of the breast will be found in the *Archives d'électricité médicale*.* See also the second edition of Messrs. Pusey and Caldwell's book for tables of cases.†

In the present stage of our knowledge little can be done beyond the collation of the views of different writers who have experience in the matter. In the weekly epitome of the *British Medical Journal* for June 6, 1903, many valuable abstracts will be found, in fact the whole of that number of the Journal is a mine of information on the subject of X ray therapeutics, as may be seen from the numerous references already made in this chapter to papers in that number. The following abstract is reproduced almost in its entirety, as it brings out clearly the frequent disappointments which fall to the lot of all who work at the treatment of cancer by X rays, and lays an emphasis upon the failures which is perhaps not sufficiently evident in all writings on the subject.

E. A. Codman‡ states that at the Massachusetts Hospital many cases of deep malignant disease have been faithfully exposed, but few have essentially improved and none have been cured. There have been a few encouraging signs in some cases as relief from pain, gain in weight, shrinkage, softening, breaking down of the tumour, &c., but since these events occur in the course of untreated malignant disease the positive advantage of the X ray can hardly be proved. On the other side, of cases of epithelioma,§ about a hundred have healed or are healing. Occasionally one is referred to the surgical department for excision.

In an unusually hopeful case of cancer of the tongue operated on in April, 1902, as far as could be seen the disease was entirely removed and the wounds healed well. The X rays were begun in May for prophylaxis, and although the floor of the mouth and sides of the neck of the patient were kept on the edge of troublesome dermatitis until September, the disease by that time had so far recurred in the mouth and neck as to make the X ray a mere nuisance. A case of cancer of the breast, which had never been operated upon, was treated by X rays

* November, 1893.

† *Vide* supra, p. 444 (footnote).

‡ *Johns Hopkins Hospital Bulletin*, May 1903.

§ This probably means rodent ulcer.

from October, 1902; the skin was kept constantly exfoliating and at times blistered. The growth remained practically the same on April 14, 1903. In a breast case operated on in October, 1901, there were seven spots of cutaneous recurrence on December 4, 1902, about the size of lemon seeds. These were in the skin rather than below the skin, but were not ulcerated. All seven spots had disappeared on April 14, 1903. Thus in some cases it is possible to remove by the X ray the recurrent skin nodules. Two cases of cancer of the penis had been treated without success. In one case the cancer was but $\frac{1}{4}$ inch in diameter, but was so obstinate to X ray treatment that an amputation was done.

In the case of a patient with sarcoma of the sterno-clavicular region, a small incision had been made and a piece of the growth removed. It was found to be a round-celled sarcoma, and as the case proved to be inoperable, X ray treatment was begun in November, 1902. At that time the tumour measured 5 inches by $2\frac{1}{2}$ inches. In April, 1903, nothing remained but a slight thickening about and behind the clavicle. The weak point of the case is that when the tumour subsided a subluxation of the clavicle was revealed. This fact suggested that the periosteum might have been torn and have formed a callus. Codman adds that he has seen other cases of sarcoma faithfully followed by the X ray and yet steadily grow worse. Referring to "certain rosy articles on the use of the X ray in the more terrible forms of malignant disease, of the disappearance of sarcoma and cancer," Codman says that at the Massachusetts Hospital they did not get such results, and in his private practice he did not get such results. He says, however, that the effect of the X ray in causing the disappearance of psoriasis, chronic eczema, lupus and superficial epithelioma (rodent ulcer) is little short of the miraculous. In some cases recurrence takes place, perhaps after too brief treatment. He believed, too, that though few reliable reports of success in deep cancer and sarcoma had yet appeared, considering the immense number of such cases which have been treated, the X ray offered at least some hope. It seemed to him that the effects were due to stimulation of the nutrition of the parts rather than to destruction of the malignant tissue, because:—(1) The effect often did not take place for days and sometimes for weeks. (2) From the analogy of so-called burns the primary

effect was increased stimulation of the skin as evidenced by hyperæmia and exfoliation. (3) In one case of massive malignant disease of the breast which had been long and faithfully exposed no destruction of the cells was found. Degeneration in the interior of such cancers which had not been treated was often found. (4) The appearance sometimes found of shrunken cancer cells surrounded by granulation tissue might be explained by the activity of the tissue. (5) In a case of varicose eczema of the leg which he treated the eczema not only disappeared, but the leg shrank to its normal size and its circulation became active. (6) The good effects occurred chiefly in those diseases characterized by a disordered or indolent local nutrition, which Nature, when stimulated by other means, had at least a chance of throwing off. For instance, they all knew that chronic eczema, psoriasis, lupus, rodent ulcer, epithelioma, even ulcerated cancer of the breast, might under improved conditions heal in whole or in part. Even in deep-seated malignant disease they might find cases of spontaneous absorption of sarcoma, perhaps coincident without some outlandish treatment. (7) That of the above-mentioned forms of disease Nature was more likely to help in those in which the X ray was most efficacious, while in cases where the malignancy of the cancer growth was great even the X ray cannot check it. (8) That good and bad effects alike occurred chiefly in the skin, the nutrition of which seemed in a more delicate balance than that of the deeper tissues. His method was to expose for ten minutes at 10 inches as a standard dose; to repeat this twice a week until hyperæmia appeared or the end of the third week was reached. By this means the accumulated dose at the end of the third week only reached 60 minutes at 10 inches, then if necessary he would increase the dose, never allowing a burn of the second degree if it could be avoided, but keeping the parts hyperæmic, pigmented, or exfoliating. In most individuals slight dermatitis usually appeared in from two to three weeks. In one case he caused a slight dermatitis by an exposure equivalent to 15 minutes, but usually it required from four to ten exposures of ten minutes each at ten inches distance to cause dermatitis. In his experience the tide turned in epithelioma (rodent ulcer ?) at about the same time as dermatitis appeared. He did not believe that it was yet justifiable to use the destructive power of of X ray to cause necrosis in the manner of the old-fashioned

cancer pastes, &c. Finally, it should be remembered that cancer might arise in an X ray burn. Two such instances were on record already, and one sad case had occurred in Boston. Cancer appeared simultaneously in the ring fingers of both hands, necessitating amputation at the first phalanges. The hands had been in a chronic state of ulceration from an X ray burn for several years.

374. **Sarcoma.**—W. B. Coley,* reporting on 36 cases of inoperable sarcoma treated with the X rays, states that in four cases the tumours disappeared entirely, but in each case there was recurrence. In several cases in which the toxins (Coley's fluid) had been tried and failed the X rays caused disappearance of the tumours, but with speedy recurrence. He considers that in spindle-celled sarcoma the toxins have a better effect than the X rays, while the X rays have the better effect in round-celled sarcoma. Better results may follow the combination of both methods. Coley thinks that the X rays have been shown to have a decided inhibitory action on sarcoma, in certain cases sufficient to cause entire disappearance of the tumour. But there is a tendency to recurrence, and in no instance has sufficient time elapsed to consider the patient cured.

W. J. Morton has advocated the administration of quinine before each application of X rays in malignant disease, and a case† has been recently reported in which the combined use of quinine and X rays led to the disappearance of a sarcoma which had recurred several times after removal. The X rays alone without the quinine did not seem to restrain the growth in this case (see also § 339).

375. **Prophylactic use of X rays.**—It has been suggested that the best mode of employing X rays in malignant disease is to commence at an early date after the removal of the growth by operation, before any evidence of recurrence has shown itself, in the hope of preventing recurrence by destroying any microscopical foci of disease which may have escaped removal. Not much evidence has yet been collected as to the value of this procedure, but the idea appears to be a rational one. In § 373 a case is quoted where the attempt at prophylaxis failed. In a patient under my own care a course of X ray applications was given to a lady soon after the removal of enlarged glands from

* *New York Med. Jour.*, August 8, 1903.

† *Arch. d'élect. médicale*, June, 1904.

the cervical region. The breast had been removed on a previous occasion. After treatment by X rays had been continued for two months some suspicious thickening was felt underneath the scar of the second operation wound. An operation was performed and the suspicious region was excised. A microscopical examination revealed fibrous tissue containing a few cells of suspicious character, but not of such a kind as to enable a diagnosis of carcinoma to be made with any certainty. It is interesting to remark that the tissues removed at the operation which preceded the use of X rays were distinctly carcinomatous with abundance of epithelial elements, and it is therefore quite possible that the X ray applications had altered the character of the recurring growth in a beneficial way, although they had not succeeded in preventing recurrence altogether.

376. **Radium.**—This is a metal belonging chemically to the same natural group as calcium, strontium, and barium. Of this series it is the highest member, its atomic weight being 225, which places radium very high among elements of high atomic weight. It is found in minute amount in certain ores of uranium, and it is suspected to be a product of the decay of that element, but if so it represents only a single stage, for it is itself unstable and in a state of change, passing through several stages and forming another element, helium, of very small atomic weight. Rutherford states that there are two well marked changes in uranium, five in thorium, and six in radium; and that it is probable that a closer examination of the active products may lead to the discovery of still further changes.

Radium salts give a red colour to the Bunsen flame.

The discovery of radium followed the observation of Becquerel that uranium and its compounds had the property of affecting a photographic plate through an opaque layer of black paper, a discovery which was prompted by Röntgen's discovery of X rays. It was found that pitch-blende, an ore of uranium, had an effect as powerful as that of pure uranium, though containing only 50 or 60 per cent. of that metal. Madame Curie drew the inference that this peculiarity might be due to the presence in pitchblende of small quantities of some more active body, and prosecuting researches in this direction finally discovered and isolated radium.

Radium is the most remarkable of a series of "radio-active" bodies, which includes also uranium, thorium, and perhaps

others. Their existence is determined by the photographic method already referred to, or by the more delicate method of observing the rate of discharge of a charged electroscope to which the radio-active body is brought near. This effect is due to their power of ionising the air, and so rendering it a conductor of electricity.

Radium compounds emit three kinds of "radiation" known respectively as alpha, beta, and gamma rays. The alpha rays are positively charged material particles whose mass is computed to be twice that of the atom of hydrogen. They are emitted with great velocity, about 20,000 miles a second, and are thought to be atoms of helium. The beta rays are negatively charged electrons, and are comparable to the negative electrons which constitute the kathode stream of an X ray tube (§ 341), and the gamma rays are ethereal radiations produced by the beta rays, just as X rays are produced by the impact of the kathode rays upon the anti-kathode of an X ray tube. The gamma rays resemble X rays in their power of penetration, the beta rays have very little penetrating power, and the alpha have even less.

Radium and thorium also emit a gas or "emanation" which is radio-active.

377. **Radio-active emanations.**—Professor Rutherford* in writing of this subject says that a most important and striking property possessed by radium, thorium and actinium, but not by uranium or polonium, is the power of continuously emitting into the surrounding space a material emanation which has all the properties of a radio-active gas. This emanation is able to diffuse rapidly and may be condensed by extreme cold. The emanation rapidly loses its activity with time.

Radium and thorium have the further peculiar power of exciting temporary radio-activity on all bodies in their neighbourhood. A substance which has been exposed for some time in the presence of radium or thorium, behaves as if its surface were covered with an invisible deposit of radio-active material. The "excited" body emits radiations capable of affecting a photographic plate, and of ionizing a gas. Unlike the radio-active elements themselves however, the activity of the body does not remain constant after it has been removed from the influence of the exciting active material but decays with time.

* "Radio-activity," by E. Rutherford. Cambridge University Press, 1904.

The activity lasts for several hours when due to radium, and for several days when due to thorium. An examination of the conditions under which excited activity is produced shows that there is a very close connection between the emanation and the excited activity (Rutherford).

It has been proposed to employ this excited radio-activity in treatment, on account of the cost of the salts of radium. A piece of platinum foil, for example, could be exposed to the emanations of radium and would then for a time have the same therapeutic action as the radium compound itself.

The radio-activity of uranium, thorium and radium has been shown to be maintained by the production at a constant rate of new kinds of matter which possess temporary activity. The steady activity of the radio-elements is due to a state of equilibrium with the rate of production of new active matter compensating for the decay of that already produced. In some cases the active products possess well defined chemical properties different from those of the parent elements, and can be separated from them by chemical means. In other cases the new products, as in the case of the thorium and radium emanations, are gaseous in character, and are released from the radio-elements by a process of diffusion. These emanations have been shown to possess the properties of gases. They possess the property of being occluded in some bodies, including the compounds of the radio-elements themselves, and they are liberated by heating or solution (Rutherford).

Other radio-active products are not gaseous, but attach themselves to the surface of bodies and can be removed from them by solution or heating. The emanation X of thorium, for example, possesses some chemical properties which distinguish it not only from the emanation from which it is derived, but also from the other active product thorium X.

The alpha rays play by far the most important part in radio-active processes. Most of the energy radiated in the form of ionizing rays is due to them. In addition most of the active products emit only alpha rays. The beta and gamma rays in most cases only appear in the last stage of the radio-active process.

378. **The action of radium on micro-organisms.**—Alan B. Green* has made investigations upon the germicidal action

* *Proc. Roy. Soc.*, May 5, 1904.

of radium emanations, and the induced radio-activity of micro-organisms exposed to the emanations. One centigramme of pure radium bromide, contained in a vulcanite and brass capsule fronted with thin talc, was employed. This specimen caused pigment to disappear after eighteen days from a mole with fifteen minutes' exposure, the talc being in contact with the skin; twenty minutes' exposure almost produced ulceration. The bacterial growth was spread as a thin film in the centre of the depression of a hollow ground glass slide, around the circumference of which depression a metal ring had been cemented. The capsule containing the radium bromide was placed upon this ring so that the salt was within one to two millimetres of the bacteria, nothing separating them but the talc and the intervening air.

Calf vaccine with its contained extraneous genus, S. pyogenes aureus and albus and S. cereus flavus and albus, were first exposed, exact control experiments being made. The specific germ in no case survived a longer exposure to radium than twenty-two hours, at the end of which time it had completely lost its ability to cause any visible irritation at the site of inoculation on a calf. In seventeen out of twenty-five experiments it was destroyed after ten hours. The extraneous germs were destroyed in rather less time, in no case surviving after fifteen hours.

Several other species of micro-organisms were tested. All the non-spore-bearing bacteria were killed after two to fourteen hours' exposure. Bacteria containing spores were by far the most resistant, for they were not killed with less than seventy-two hours' exposure. As the distance between the radium and the micro-organism was increased the germicidal action became less marked, so that after thirty hours' exposure at one centimetre all were not killed though the numbers were lessened, and at ten centimetres there was no apparent action. After exposure at a distance of one millimetre to the radium emanations for twenty-four to a hundred and twenty hours, micro-organisms themselves may show signs of radio-activity, and affect a photographic plate, the best results being obtained from bacterial masses containing a number of spores. Radio-active micro-organisms have continued to give off photo-actinic emanations after three months have elapsed since their exposure to radium.

379. **Other physiological effects.**—Danysz* found that the action of radium on the skin is never immediate. At first nothing is felt, but on the eighth, fifteenth, or even twentieth day there is some congestion. This long latent period is one of the most interesting and mysterious facts about the action of Becquerel rays on living tissues. A sample of barium chloride containing about 50 per cent. of pure radium is, according to M. Curie, 500,000 times more powerful than metallic uranium, and produces an appreciable congestion of the skin in a few minutes. If placed in contact with the skin of a guinea-pig for twenty-four hours, it causes complete destruction of the epidermis and dermis. Contact for forty-eight hours does not produce any deeper ulceration. The deeper connective and muscular tissues are little affected. If the radium be placed under the skin a relatively feeble effect is produced on the epidermis, and even less on the connective tissues and muscles. The epidermic tissues seem to absorb the rays that produce the pathological effects. The skin of the guinea-pig is much more sensitive than that of the rabbit ; indeed an exposure that produces alopecia in the guinea-pig may cause a growth of hair in the rabbit. A tube of radium placed for one to four months in the peritoneal cavity produced no lesions comparable to those on the skin, and the intestines and serous membranes seem to be very slightly sensible to these radiations.

The nervous system is much more sensitive than the epidermis. A tube of active radium placed under the skin over the vertebral column and part of the cranium of a young mouse one month old, caused at the end of three hours paresis and ataxia, after seven to eight hours tetaniform convulsions, and death in twelve to eighteen hours. Mice, three to four months old, died with the same symptoms in three to four days, and those one year old in six to ten days. Guinea-pigs, eight to twelve days old, similarly treated for twenty-four to forty-eight hours, but with the tube applied to the lumbar region, suffered in one to three days from complete paralysis of the hind quarters and tetaniform convulsions. Death ensued in six to eight days. Adult guinea-pigs and rabbits treated in the same way did not show any nervous troubles immediately, but died with skin lesions some weeks or months afterwards. An adult rabbit in

* *Acad. des Sciences*, Feb. 16, 1903. See also *British Medical Journal*, Feb. 13, 1904.

which a tube was placed under the dura mater for eight hours showed nothing abnormal for two days, but on the third it had hemiplegia. It would seem, therefore, that the nerve centres sensible to these rays are very effectively protected by the bone in adults, while the cartilaginous tissues of young animals do not afford much resistance to the passage of the rays.

The larvæ of insects kept in a tube with radium for twenty-four hours died in two or three days; in them, too, the nervous system was most affected. When soluble salts of radium are dissolved in distilled water the emanations are dissolved by the water, and act on insect larvæ much like the substance itself.

Becquerel's rays affect microbes in varying degree. In all development is interfered with, but some—and notably those that produce proteolytic autodigestion—are killed under certain conditions. The bacilli of anthrax fail to develop if they are placed for twenty-four hours in contact with these emanations.

The effects on animals so far described were produced at close range, but the rays emitted by radium can also kill at a distance. London has found that if 30 mg. of radium be placed over a cage of mice for one to three days the animals become ill on the third day, and die on the fourth or fifth. The first effects are redness of the ears and blinking of the eyelids; then follow drowsiness, refusal of food, slowness of movement, and feeble response to mechanical stimuli. At the fourth day there is coma with paralysis of the hind legs. In deepest coma the spinal reflexes may be exaggerated and the respirations slow and even scarcely appreciable. There is thus marked depression of the cerebral nervous system and exalted excitability of part of the cord. The respirations finally cease, and death occurs. After death the hairs on the back could be pulled out in masses, and often the epidermis came with them. The subcutaneous tissue was greatly congested. The chief histological changes were produced in the skin and cortex cerebri.

The effects of radium on the blind are interesting. Blind persons slightly susceptible to light get a sensation of light when radium is placed over one or other eye. Persons who can just distinguish light from shade, but cannot distinguish form, when placed in a dark room, can distinguish the outlines of an object projected on or placed in a screen illuminated by radium.

Radium rays exert a marked influence on the eggs of sea urchins, which in the course of development pass through the three stages—ciliated blastula, the hollow gastrula, and the pluteus larval stage. If blastulæ are exposed to radium rays for forty minutes the gastrula is not formed, though the ciliary movements become more intense. If gastrulæ are exposed, the pluteus is small and atrophied. Spermatozoa are rapidly enfeebled and killed by these rays, while ova may be more readily fertilized. Ova exposed to radium rays may develop irregular embryos by parthenogenesis without the action of a spermatozoon. These results may be due to the action of the rays on the chromatin of the nuclei, augmenting its activity or destroying it according to the length of exposure—that is, the rays kill the spermatozoid, a mass of chromatin, but excite the ovum protected by its protoplasm, and cause parthenogenesis.

They do not seem to have a specific action on definite tissues. They act on the ectoderm of tadpoles and on the endoderm of gastrulæ of sea urchins, probably because the cells are in a state of evolution and differentiation. In man the skin, which is always being renewed, is attacked, not the muscle.

The causes of these remarkable changes in normal and pathological tissues are not fully ascertained. Whether they be caused by ultra-violet light rays, by Röntgen or Becquerel rays, there is always a primary cell degeneration, followed by secondary inflammatory reaction. Professor O. Giesel states that paper in which radium preparations have been preserved for a long time becomes brown and brittle, the celluloid loses its solidity, and it is obvious that radium rays cause molecular disturbance. This may explain the results in animal and vegetable tissues.

380. **Therapeutic applications.**—Radium has been applied to the treatment of the conditions for which X rays have been found useful. It has been successful in cases of rodent ulcer and in lupus. It is applied by means of glass tubes containing five or ten milligrammes of radium bromide which are held or fixed close to the affected part. It is also enclosed in small capsules with a cover of mica, which permits of the escape of beta rays to a small extent as well as of the gamma rays.

Radium rays give rise to burns of the skin like those caused by X rays, and the scars of these burns are often deeply pigmented.

Among the earliest cases in which radium was used for treatment were those of Dr. Holzknecht, viz., a successfully treated case of psoriasis vulgaris exposed for one minute, a case of lupus of the face exposed for seven minutes, a case of epithelioma of the cheek (rodent ulcer) exposed twice for five minutes and one of telangiectasis plana of the whole left upper extremity. In this eight spots of half a centimetre in diameter had been exposed for ten minutes to the rays, with the result that eight spots of the same size, consisting of perfectly normal and white skin, were visible amidst the red surface of the nævus.

G. Sichel* has reported and figured a case of rodent ulcer treated successfully by radium bromide. Five milligrammes were used, enclosed in a glass tube. There were forty-two applications spread over ten weeks. Each lasted fifteen minutes. A depressed, slightly indurated scar was left. In the same journal a report by Mackenzie Davidson on five cases treated with radium will also be found. The writer states that the quantity used by him in these cases was five milligrammes. It was enclosed in a glass tube and this was affixed with adhesive plaster to the affected part. Exposures of ten, fifteen or twenty minutes were given, and in some cases even longer. In one of the cases recorded, there were exposures of fifty and sixty minutes, but these provoked severe reaction. Two of the cases were rodent ulcer. One was a tubercular patch of the skin of the palm. One was a malignant degeneration in a mole, and the remaining one was either rodent ulcer of very severe type or carcinoma. All were cured except the last, and that was considerably relieved and was cicatrising at the time of writing.

Other papers on the medical applications of radium will be found in the *British Medical Journal*:—"The Nature and Physiological Action of Radium Emanations and Rays," by Dawson Turner, Dec. 12, 1903; "Radium and its Therapeutic Effects," by John Macintyre, July 26, 1903; "On the Therapeutic Effects of the Salts of Radium," by John Macintyre, July 23, 1904; "The Position of Radium in Therapeutics," by C. M. O'Brien, with reports of two cases of lupus treated successfully by radium, July 25, 1903.

In the same number of the Journal will be found a suggestion from Mr. F. Soddy that the radio-active emanation of thorium

* *Brit. Med. Jour.*, Jan. 23, 1904.

might be used in pulmonary diseases as an inhalation. Bouchard, Balthazard and Curie have shown that the introduction of radium emanation into the lungs of animals gives rise to toxic effects, the dominant lesion observed on post-mortem examination being an intense pulmonary congestion, *Acad. Sciences*, June, 6, 1904. See note in *Nature*, June 16, p. 167.

381. **The constitution of matter.**—The phenomena exhibited by the radio-active bodies have thrown fresh light upon the composition of matter.

Sir Oliver Lodge* in a popular article on this subject points out that the atom of hydrogen probably contains about eight hundred electrons, but that they are very sparsely distributed within the atom so that there is plenty of room for them, and goes on as follows:—"Some atoms contain many more than this number and the tightest packing known exists in the atoms of the radio-active substances, uranium, radium, and the like, each atom of which contains something like two hundred thousand electrons. Even this is very far from tight packing, the intervening spaces are still very great compared with their size, but they are getting too crowded to be comfortable, and nature does not seem to have evolved any permanent atom more tightly packed than these. Moreover even these are not quite stable and permanent, every now and then a particle escapes and flies away from one or another atom into space, so that if we take a perceptible quantity of the substance—which, of course, consists of many billion atoms—a considerable number of particles are always being shot off from it; hence a substance composed of these heavy atoms maintains a continuous bombardment, emitting rays analogous to those which Crookes had so strikingly exhibited in 1879 in an exceptionally high vacuum tube. The experimental discovery of spontaneous radio-activity is due to M. Henri Becquerel in Paris in the year 1896, one year after Röntgen's singular discovery of the existence and electrical generation of X rays.

"Our present view of an atom of matter therefore is something like the following:—Picture to oneself an individualized mass of positive electricity, diffused uniformly over a space as big as an atom, say a sphere of which two hundred million could lie edge to edge in an inch, or such that a million million million million could be crowded tightly together into an apothecary's grain.

* "The Electric Theory of Matter," *Harper's Magazine*, Aug. 1904.

Then imagine disseminated throughout this small spherical region a number of minute specks of negative electricity all exactly alike, and all flying about vigorously, each of them repelling every other, but all attracted and kept in their orbits by the mass of positive electricity in which they are embedded and flying about.

"In so far as an atom is impenetrable to other atoms, its parts act on the sentinel principle, not on the crowd principle. There are two ways of keeping hostile people out of an open building: one is to fill it with your own supporters, another is to place an armed policeman at every door. The electrons are extremely energetic and forcible, though in bulk mere specks or centres of force. Every speck is exactly like every other, and each is of the size and weight appropriate to the electron. Different atoms, that is atoms of different kinds of matter, are all believed to be composed in the same sort of way; but if the atoms of a substance are such that each possesses twenty-three times as many electrons as hydrogen has, we call it sodium. If each atom has 200 times as many as hydrogen, we call it lead or quicksilver. If it has still more than that, it begins to be conspicuously radio-active.

"It would seem as if the excessive radiation which follows upon an overcrowded condition were caused by the probability of collision or encounter between the parts of an atom: just as every now and then among the stars in the sky two bodies encounter each other, and a great blaze of radiation, or temporary star, results. Even in atoms of which the parts are sparsely distributed such occurrences are not impossible, though they are less frequent, and accordingly it is to be expected that every kind of matter may be radio-active to a very small extent: a probability which is now justified for most metals, by direct experiment with very sensitive means of detection.

"Indeed, so far as radiation necessarily accompanies any change of motion of an electron, and in so far as in every atom some electrons are describing orbits and are therefore subject to centripetal acceleration, a certain amount of atomic radiation is inevitable, on the electric theory of matter. In most cases it is imperceptibly small, but it must be there, and accordingly an atom must be slowly undermining its own constitution by the gradual emission of its internal or intrinsic energy in the form of ether waves.

"Thus then it is reasonable to expect that, every now and then, an atom will break up or collapse or divide into parts. This process has been observed by Rutherford, of Montreal. The radiation from many of the radio-active substances, on being analyzed by a magnet, is found to be separable into three parts:—(1) the so-called β rays, which are the shot-off electrons already mentioned; (2) some γ rays, which appear to represent an ethereal pulse—an analogue as it were of the sound-wave caused by the explosion or act of firing; and (3), more important than either, a third kind of projectile called the α rays, which are newly formed atoms of foreign matter or new substance. These are pitched away with extraordinary violence as the atom breaks up, they produce by their bombardment of zinc sulphide the bright little flashes seen in Crookes' spinthariscope, and they likewise generate heat when they are stopped by any obstacle. They thus keep the vessel in which they are enclosed at a temperature a degree or two above surrounding bodies, at least in the case of the most active known substances, radium and its emanation. For radium converts its own intra-atomic energy into heat at so surprising a rate that it could, if all of the heat were economized and none allowed to escape, raise its own weight of water from ordinary temperature to the boiling-point every hour.

"The number of atoms breaking up in any perceptible portion of radium salt must be reckoned in millions per second; nevertheless the *proportion* of atoms which are thus undergoing transformation at any one time is extremely small. If they could be seen individually most of them would appear quiescent and stable. Of every ten thousand atoms, if a single one breaks up and flings away a portion of itself once a year, that would be enough to account for all the activity observed, even in the case of so exceptionally active a substance as radium; hence the apparent stability of ordinary matter is not surprising.

"The thus-projected atomic fragments were measured by Rutherford, who found them deflected by a magnet in the opposite direction to the electron projectiles, and were therefore proved to be positively charged but they are deflected so slightly that they must be very massive bodies, 1600 times as massive as an electron, or twice the atomic weight of hydrogen. A substance with this atomic weight is known, viz., helium; and surely enough the discoverer of helium, Sir W. Ramsay,

working with Mr. Soddy, a recent colleague of Rutherford, has witnessed the helium spectrum gradually develop in a tube into which nothing but radium emanation had been put.

"Matter then appears to be composed of positive and negative electricity and nothing else. All its newly discovered, as well as all its long known properties can thus be explained."

APPENDIX.

List of Towns with Direct Current Supply.

PROVINCIAL.

Town.	Pressure of supply. Volts.	Town.	Pressure of supply. Volts.
Aberdeen	220	Blaenau Festiniog	220, 230
Aberystwith (in part)	100, 220	Blyth and Cowpen	230
Accrington	230	Bolton (in part)	230
Alderley Edge	210	Bootle	220
Aldershot	210	Bournemouth (in part)	480
Alloa	220	Bradford	230
Alnwick	230	Brechin	240
Ashton-under-Lyne	240	Brighouse	110
Aston Manor	230	Brighton	115, 230
Atherton (in part)	500	Bristol (in part)	250
Ayr (in part)	250	Broadstairs	240
Banbury	230	Bromley (Kent)	210
Bangor (Wales)	200	Broughty Ferry	230
Barking	230	Buckingham	100
Barnes	210	Burnley	220
Barnsley	230	Bury	220
Barnstaple	230	Bury St. Edmunds	200
Barrow-in-Furness	220	Buxton	230
Bath (in part)	220	Camborne	240
Batley	220	Canterbury	220
Belfast	220	Cardiff (in part)	200
Berwick-on-Tweed	240	Carlisle	230
Bexhill-on-Sea	220	Carlow (in part)	100, 200
Birkdale	230	Caterham	420
Birkenhead	230	Chelmsford (in part)	100, 200
Birmingham	220	Cheltenham (in part)	100, 200
Blackburn (in part)	220	Chester	210
Blackpool (in part)	200	Chesterfield	240

Town.	Pressure of supply. Volts.	Town.	Pressure of supply. Volts.
Chislehurst	210	Godalming	240
Chiswick	220	Gorseinon	200
Christchurch	250	Govan	250
Cleckheaton	230	Grantham	240
Coatbridge and Airdrie	240	Gravesend	230
Colchester	210	Grays Thurrock	230
Colne	240	Greenock	250
Colwyn Bay	220	Grimsby	230
Cork	230	Guernsey	210
Cowes	240	Guildford	215
Crewe	230	Halifax (in part)	230
Cromer	240	Hamilton	240
Croydon (in part)	230	Harrington	115
Darlington	230	Harrow	220
Dartford	230	Hawick	240
Dartmouth	240	Hebburn	230
Darwen	230	Heckmondwike	230
Devonport	230	Hereford	220
Dewsbury	220	Heywood	200
Diss	200	High Barne	230
Doncaster	230	High Wycombe	210
Dover (in part)	500	Hornsey	240
Dudley	230	Hove	220
Dundee	200	Hull	220
Durham	230	Ilford	230
East Ham	240	Ilkeston	230
Edinburgh (in part)	230	Ingleton	100 200
Epsom	230	Ipswich	230
Falkirk	230	Jarrow	230
Farnworth	220	Keighley	230
Faversham	230	Kendal	220
Felixstowe	200	Kettering	230
Fleetwood	200	Kidderminster	230
Folkestone	210	King's Lynn	200
Fort William (in part)	150	Kirkcaldy	230
Galway	110	Lancaster	100, 200
Gateshead (in part)	230	Leamington	115, 230
Glasgow	250	Leatherhead	220
Glossop	240	Leigh	220
Gloucester	220	Leith	230

Town.	Pressure of supply. Volts.
Lewes	230
Leyton	150
Limerick	230
Lincoln	230
Liverpool	230
Liverpool District	220
Llandilo	230
Llandrindod Wells	230
Llandudno	220
Long Eaton	220
Longton	230
Lowestoft	230
Luton	250
Lymington	240
Maidstone	230
Manchester	100, 200
Mansfield	240
Margate and Broadstairs	240
Market Drayton	240
Melrose	225
Melton Mowbray	240
Merthyr Tydfil	230
Mevagissey	110
Mexborough	220
Middlesbrough	220
Middleton	220
Milford-on-Sea	230
Montrose	240
Morecambe	220
Motherwell	230
Nelson	230
Newbury	240
Newcastle (in part)	240
Newmarket	210
Newport (I. W.)	240
Newton Abbott	240
Northallerton	220
Northampton	210
Northwich	220
Norwich	220

Town.	Pressure of supply. Volts.
Nottingham	200
Nuneaton	220
Ogmore Valley (in part)	100, 220
Oldham	210
Oswestry	220
Oulton Broad	230
Oxford	100
Paisley (in part)	200
Partick	240
Pemberton	230
Pembroke (Dublin)	220
Penarth	230
Perth	230
Peterborough	200
Plumstead	210
Pontypool	103
Pontypridd	220
Poole (in part)	(480)
Prescot (in part)	250
Preston (in part)	250
Queenstown	230
Rathmines	220
Reading (in part)	200
Redruth	240
Rhyl	230
Richmond (Surrey)	110, 220
Rochdale	220
Ross	230
Rotherham	230
Rothesay	230
Rottingdean	100
Ryde and St. Helens (in part)	240
St. Annes-on-Sea	240
St. Austell	110, 220
St. Helens	230
Sale	230
Salford (in part)	220
Salisbury	210
Saltburn	220
Shanklin, Sandown, and Lake	240

Town.	Pressure of supply. Volts.	Town.	Pressure of supply. Volts.
Sheerness	230	Wallasey (in part)	(500)
Shipley	230	Walsall	105, 210
Shrewsbury	210	Walthamstow	230
Sleaford	220	Warrington	230
Southampton	200	Wednesbury (in part)	230
Southend	250	Wellingborough	230
Southport (in part)	(500)	West Bromwich	230
Spennymoor	230	West Ham (in part)	(500)
Stafford	210	West Hartlepool	230
Stamford	240	Weston-super-Mare	230
Stirling	230	Weybridge	240
Stockport	320	Whitby	230
Stockton-on-Tees	230	Whitehaven	210
Stowmarket	100	Wigan	230
Sunderland	220	Winchester	210
Sutton Goldfield	230	Windsor	110, 220
Swansea	220	Witney	220
Swindon	220	Wolverhampton	220
Taunton (in part)	100, 200	Woolwich	210
Tonbridge	220	Worcester (in part)	230
Treeton	(1,250)	Worksop	220
Twickenham	240	Worthing	230
Tynemouth	220	Wrexham	230
Ventnor and Bonchurch	210	York	230

LONDON.

Battersea	230	Poplar	230
Bermondsey	240	St. James' and Pall Mall	107, 214
Charing Cross	100, 200	St. Martin's (in part)	100, 200
Chelsea	200	St. Pancras	110, 220
City of London	100, 200, 204	Shoreditch	150
Finsbury (in part)	(530)	Smithfield	100, 200
Hackney	240	Southwark	220
Hampstead (in part)	110	Stepney	240
Kensington and Knightsbridge	200	Strand	100, 200
Marylebone (in part)	100	Sydenham	100
Mayfair	210	Westminster	200
Notting Hill	200		

List of Towns with Alternating Current.

PROVINCIAL.

Periodicity.	Town.	Pressure of supply. Volts.
100.	Aberystwith (in part)	100, 220
80.	Altrincham	100
50.	Atherton*	230
60.	Ayr (in part)	100, 200
100.	Bath (in part)	100, 200
50.	Beckenham	200
60.	Bedford	105, 210
50.	Bexley (in part)	200
50.	Blackburn (in part)	110, 220
83.	Blackpool (in part)	200
83.	Bolton (in part)	100, 200
100.	Bournemouth (in part)	100, 200
60.	Bray	100, 200
93.	Bristol (in part)	105, 210
75.	Burton-on-Trent	100, 200
90.	Cambridge	200
40.	Cardiff (in part)	200
70.	Carlow (in part)	100, 200
99.	Chagford	100
100.	Chatham	100, 200
100.	Chelmsford (in part)	100, 200
100.	Cheltenham (in part)	100, 200
87.	Coventry†	200
60.	Croydon (in part)	200
40.	Derby	100, 200
100.	Dover (in part)	100, 200
50.	Dublin‡	200
40.	Ealing	102
50.	Eastbourne	200
50.	Eccles	200
50.	Edinburgh (in part)	230
50.	Erith‡	200
100.	Exeter	100
125.	Fareham	100
	Fort William (in part)	(300)
50.	Gateshead (in part)	230
50.	Gillingham‡	100, 230
100.	Hanley	100, 200
50.	Harrogate	100, 200
100.	Hastings	200
50.	Hoylake and W. Kirby	230
100.	Huddersfield	100, 200
75.	Keswick	100
100.	Killarney	100
77.	Kingston-upon-Thames	105
100.	Larne	100, 200
83.	Leeds§	100, 200
50.	Leicester	100, 200
100.	Limavady	110, 220
100.	Lynton and Lynmouth	100
100.	Magroom	230
60.	Monmouth	100, 200
60.	Morley	100, 200
50.	Neath	(2,200)
80.	Newcastle-on-Tyne	100
40.	Newcastle and Tyneside‡	(440)
87.	Newport (Mon.)	100, 200
50.	Ockerhill*	200
40.	Ogmore valley* (in part)	100, 220
50.	Paisley (in part)	200
50.	Plymouth	100, 200
100.	Poole (in part)	100, 200
50.	Portsmouth	100
100.	Prescot (in part)	100

* 2 phase. † Also 2 phase, 50 periods. ‡ 3 phase.
§ Also 50 periods, 2 phase.

Periodicity.	Town.	Pressure of supply. Volts.
50.	Preston (in part)	250
67.	Reading (in part)	200
66.	Redditch	200
50.	Reigate	200
100.	Rochester	100, 200
50.	Rugby‡	200
100.	Rugby School	100
50.	Ryde and St. Helens (in part)	240
75.	Salford (in part)	200
80.	Scarborough	100, 200
50.	Sheffield†	200
50.	Southport (in part)	100, 210
50.	South Shields	110, 220
50.	Sutton	200
60.	Taunton (in part)	100, 200
50.	Torquay	200
68.	Tunbridge Wells	220
50.	Uxbridge	100, 200
60.	Wakefield*	200
50.	Wallasey (in part)	100, 200
50.	Watford	200
50.	Wednesbury* (in part)	200
50.	West Ham (in part)	100, 200
50.	Wimbledon	220
100.	Woking	200
100.	Worcester (in part)	100, 200
83.	Yarmouth	100, 200

LONDON.

50.	Blackheath*	200
83.	Brompton	100
100.	City of London (in part)	204
50.	Deptford	200
50.	Finsbury (in part)*	104
50.	Fulham*	200
50.	Greenwich*	200
50.	Hammersmith	110
90.	Hampstead (in part)	105, 210
50.	Islington	100, 200
45.	Kensington	100
50.	Lambeth	220
60.	Marylebone (in part)	100
60.	Paddington	100, 200
60.	St. Martin's (in part)	100, 200
50.	Wandsworth*	205

The pressures of supply given in the tables are those at which current is supplied to private consumers for lighting purposes.

There is a growing tendency at present towards higher pressures, so that voltages of 200, &c., are now not uncommon. Almost all makers of incandescent lamps mark the voltage for which they are made upon the glass of the bulb. An examination of the lamps used upon a circuit will therefore indicate the voltage of the circuit; and often the candle power of the lamp and the watts (§ 28) consumed, may be learned in the same way.

The periodicity (§ 55) of alternating currents must be known before a suitable transformer (§ 137) can be selected for use on such circuits.

When an area is supplied by two phase or three phase circuits, the consumer receives single phase current, except by special arrangement, in which case he might be able to obtain a two or three phase supply.

For these lists the author is indebted to the tables annually issued by the *Electrical Review*.

* 2 phase. † Also 2 phase, 50 periods. ‡ 3 phase.

DESCRIPTION OF PLATES.

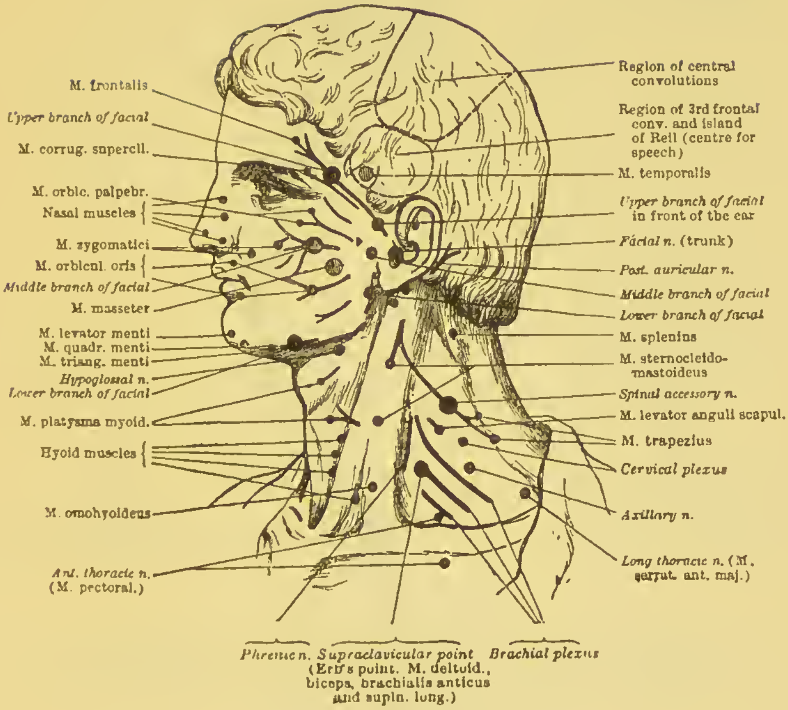
PLATES I.—VI.

The Motor Points.

PLATES VII.—XI.

The Cutaneous Nerves.

PLATE I.



M. frontalis
Upper branch of facial
M. corrug. supercil.
M. orbic. palpebr.
Nasal muscles
M. zygomatici
M. orbicul. oris
Middle branch of facial
M. masseter
M. levator menti
M. quadr. menti
M. triang. menti
Hypoglossal n.
Lower branch of facial
M. platysma myoid.
Hyoid muscles
M. omohyoideus
Ant. thoracic n. (M. pectoral.)
Region of central convolutions
Region of 3rd frontal conv. and island of Reil (centre for speech)
M. temporalis
Upper branch of facial in front of the ear
Facial n. (trunk)
Post. auricular n.
Middle branch of facial
Lower branch of facial
M. splenius
M. sternocleido-mastoideus
Spinal accessory n.
M. levator anguli scapul.
M. trapezius
Cervical plexus
Axillary n.
Long thoracic n. (M. serrat. ant. maj.)
Phrenic n.
Supraclavicular point (Erb's point. M. deltoid., biceps, brachialis anticus and supin. long.)
Brachial plexus

PLATE II.

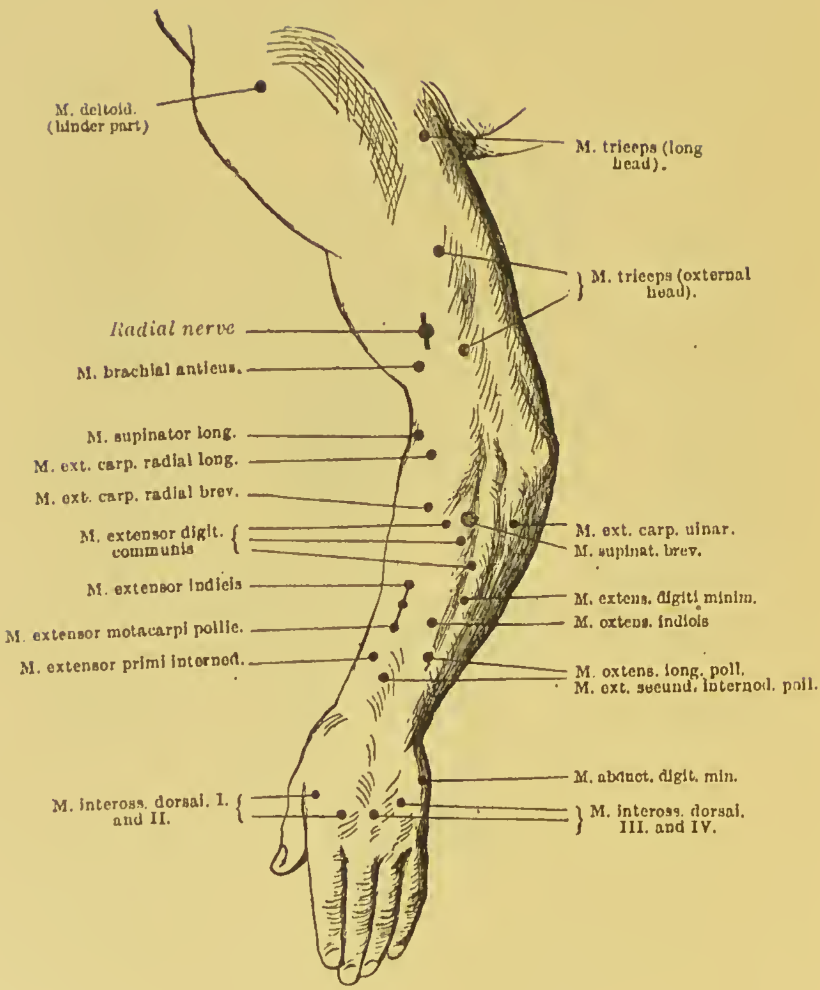

M. deltoid. (hinder part)
M. triceps (long head).
M. triceps (external head).
Radial nerve
M. brachial anticus.
M. supinator long.
M. ext. carp. radial long.
M. ext. carp. radial brev.
M. extensor digit. communis
M. extensor indicis
M. extensor metacarpi pollic.
M. extensor primi internod.
M. ext. carp. ulnar.
M. supinat. brev.
M. extens. digiti minim.
M. extens. indicis
M. extens. long. poll.
M. ext. secund. internod. poll.
M. abduct. digit. min.
M. inteross. dorsal. I. and II.
M. inteross. dorsal. III. and IV.

PLATE III

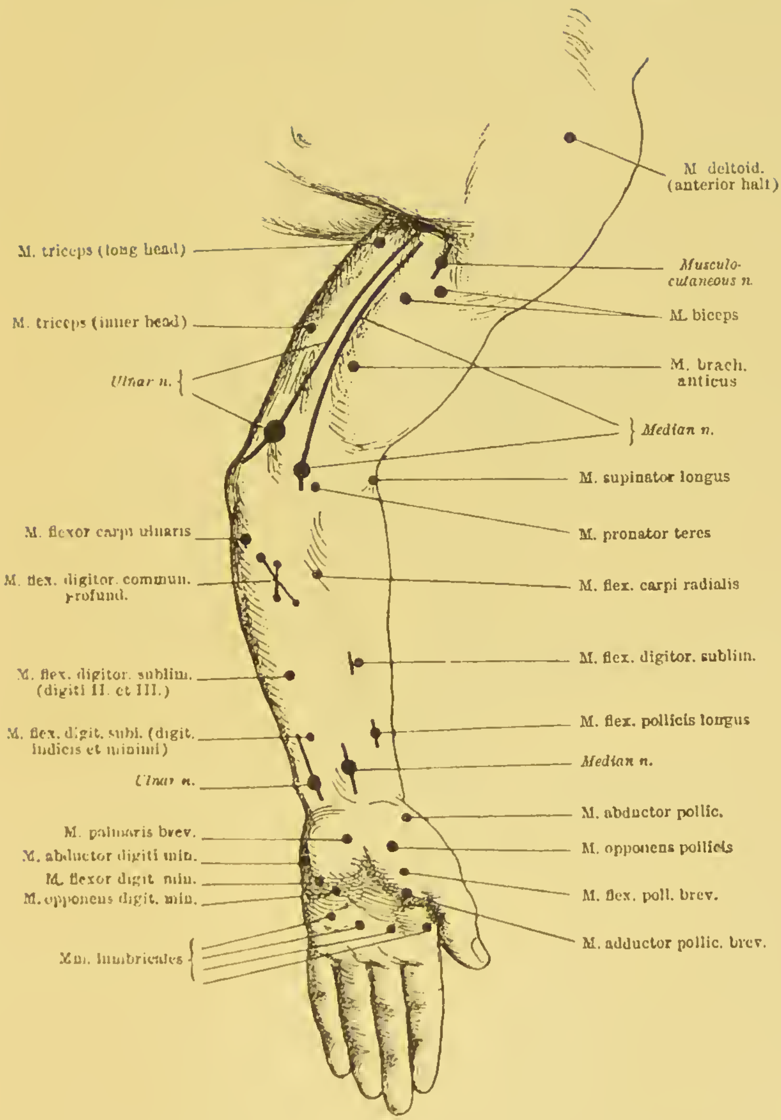
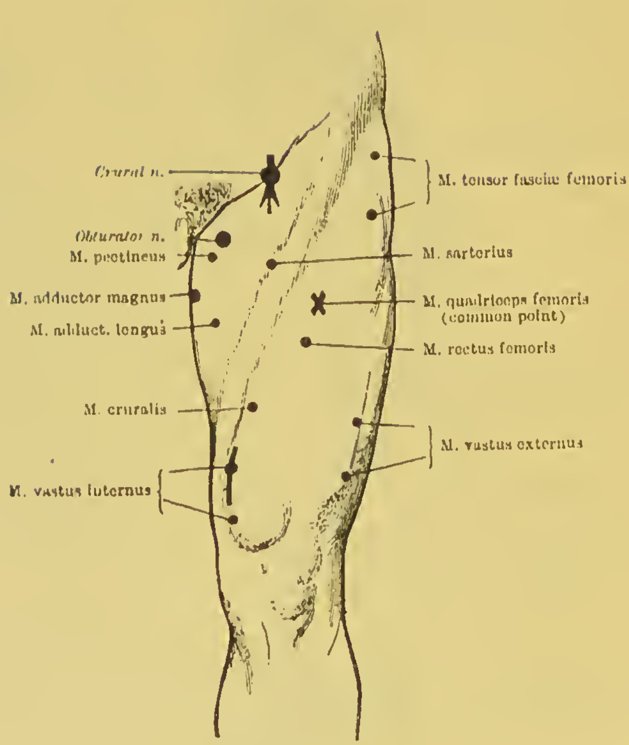

M. deltoid. (anterior half)
Musculo-cutaneous n.
M. biceps
M. brach. anticus
Median n.
M. supinator longus
M. pronator teres
M. flex. carpi radialis
M. flex. digitor. sublim.
M. flex. pollicis longus
Median n.
M. abductor pollic.
M. opponens pollicis
M. flex. poll. brev.
M. adductor pollic. brev.
M. triceps (long head)
M. triceps (inner head)
Ulnar n.
M. flexor carpi ulnaris
M. flex. digitor. commun. profund.
M. flex. digitor. sublim. (digiti II. et III.)
M. flex. digit. subl. (digit. indicis et minimi)
Ulnar n.
M. palmaris brev.
M. abductor digiti min.
M. flexor digit. min.
M. opponens digit. min.
Mm. lumbricales

PLATE IV.



Crural n.
Obturator n.
M. pectineus
M. adductor magnus
M. adduct. longus
M. cruralis
M. vastus internus
M. tensor fasciæ femoris
M. sartorius
M. quadriceps femoris (common point)
M. rectus femoris
M. vastus externus

PLATE V.

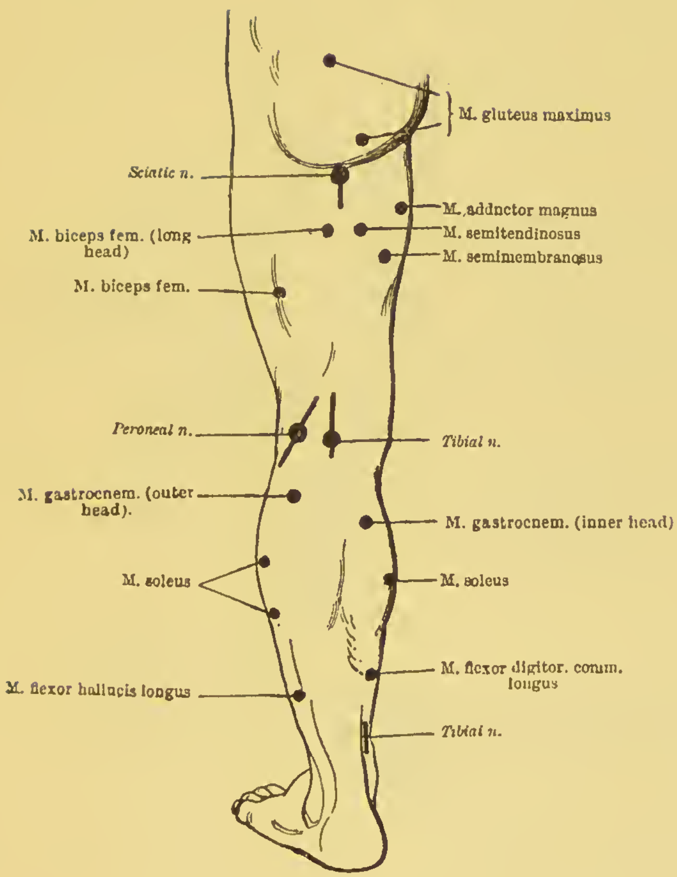
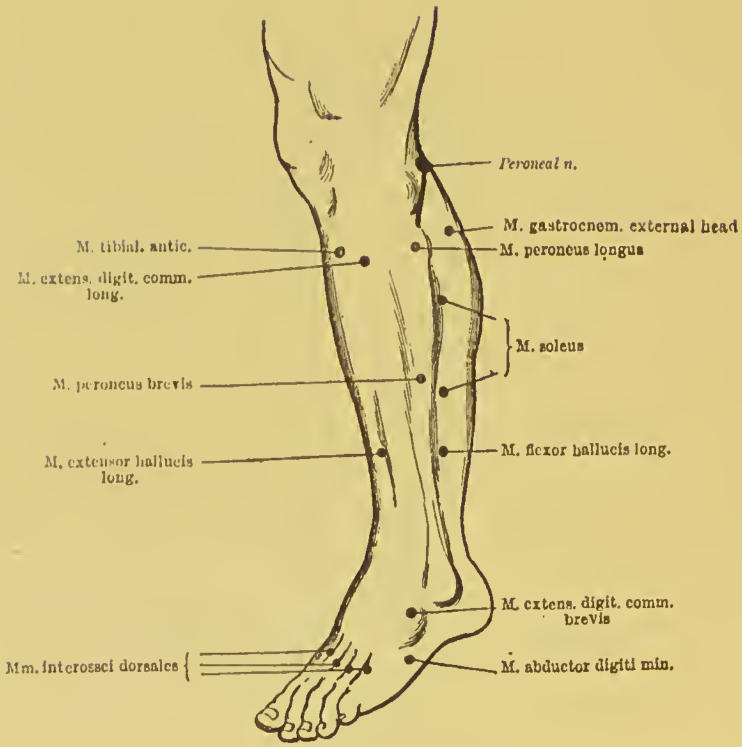

M. gluteus maximus
Sciatic n.
M. addnctor magnus
M. biceps fem. (long head)
M. semitendinosus
M. semimembranosus
M. biceps fem.
Peroneal n.
Tibial n.
M. gastrocnem. (outer head).
M. gastrocnem. (inner head)
M. soleus
M. soleus
M. flexor digitor. comm. longus
M. flexor hallucis longus
Tibial n.

PLATE VI.



Peroneal n.
M. gastrocnem. external head
M. tibial. antic.
M. peroneus longus
M. extens. digit. comm. long.
M. soleus
M. peroneus brevis
M. flexor hallucis long.
M. extensor hallucis long.
M. extens. digit. comm. brevis
Mm. interossei dorsales
M. abductor digiti min.

PLATE VII.

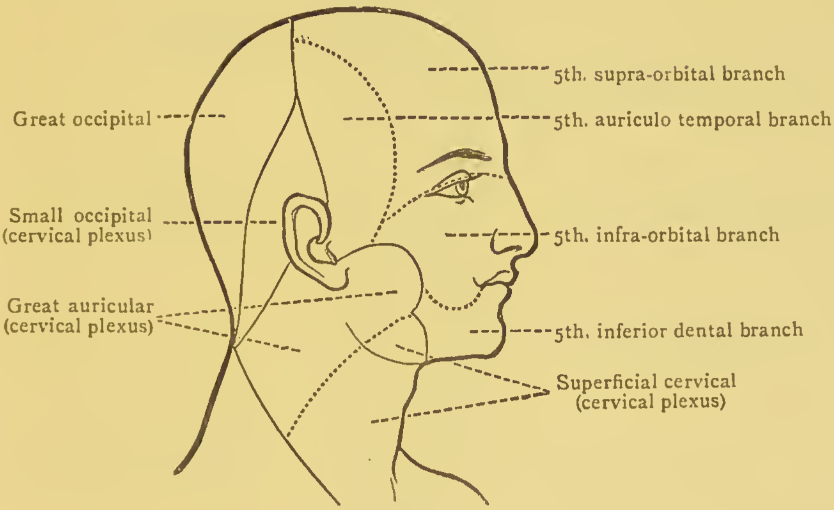

5th. supra-orbital branch
Great occipital
5th. auriculo temporal branch
Small occipital
(cervical plexus)
5th. infra-orbital branch
Great auricular
(cervical plexus)
5th. inferior dental branch
Superficial cervical
(cervical plexus)

PLATE VIII.

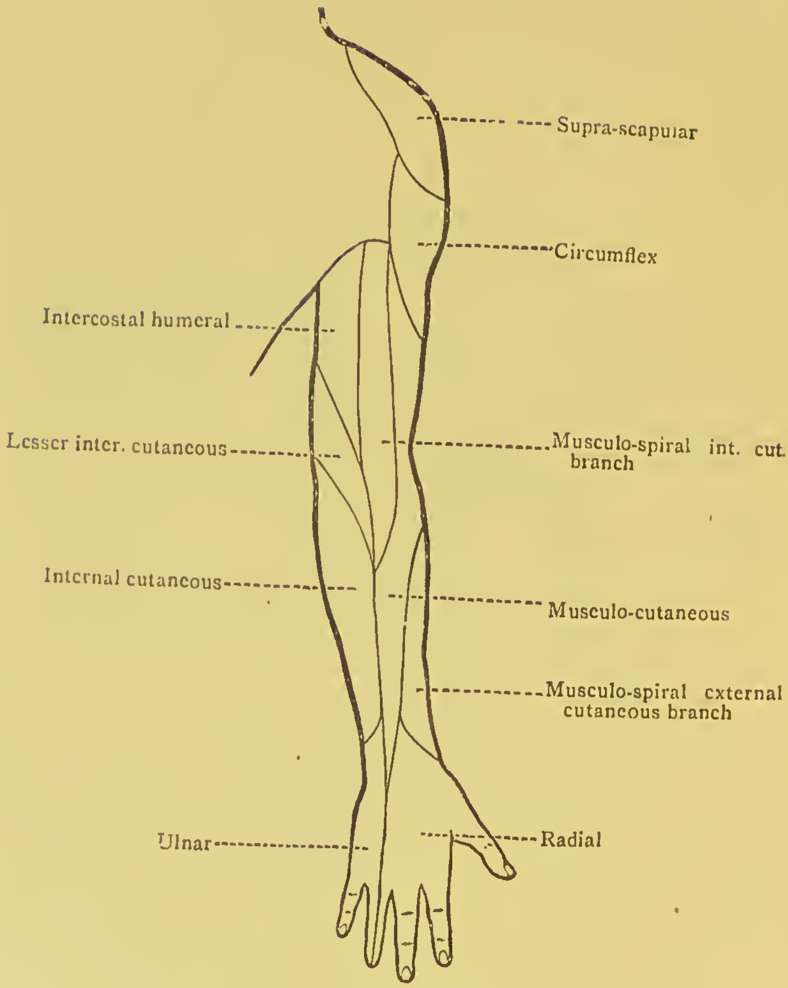

Supra-scapular
Circumflex
Intercostal humeral
Lesser inter. cutaneous
Musculo-spiral int. cut. branch
Internal cutaneous
Musculo-cutaneous
Musculo-spiral external cutaneous branch
Ulnar
Radial

PLATE IX.

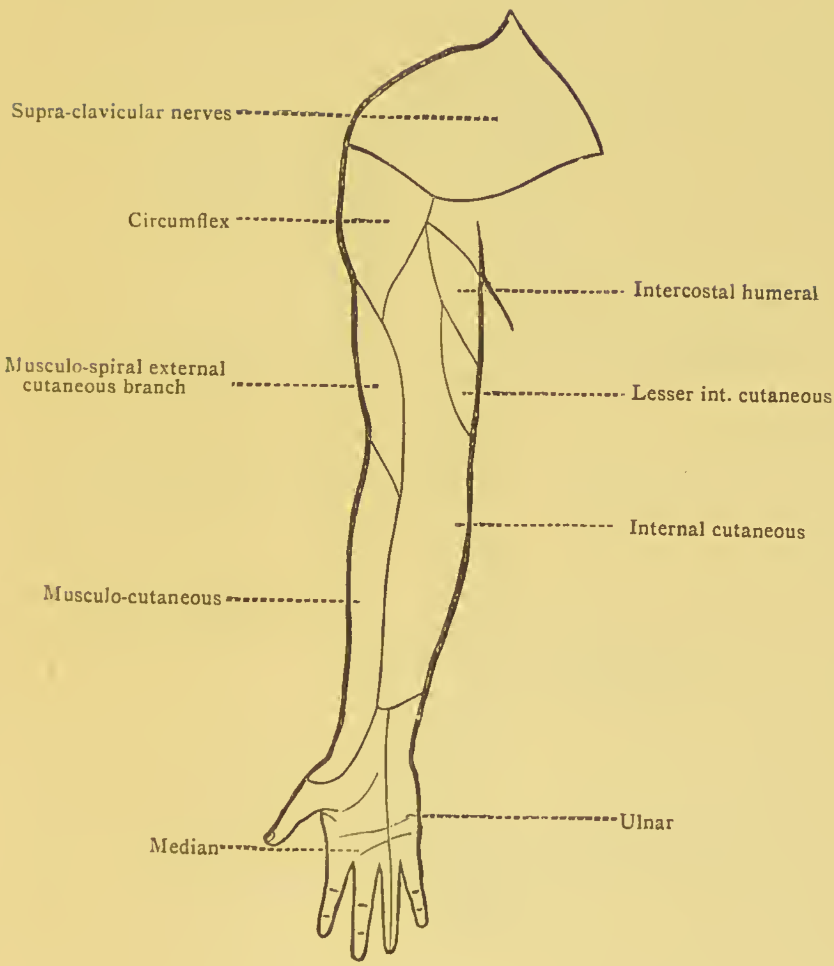
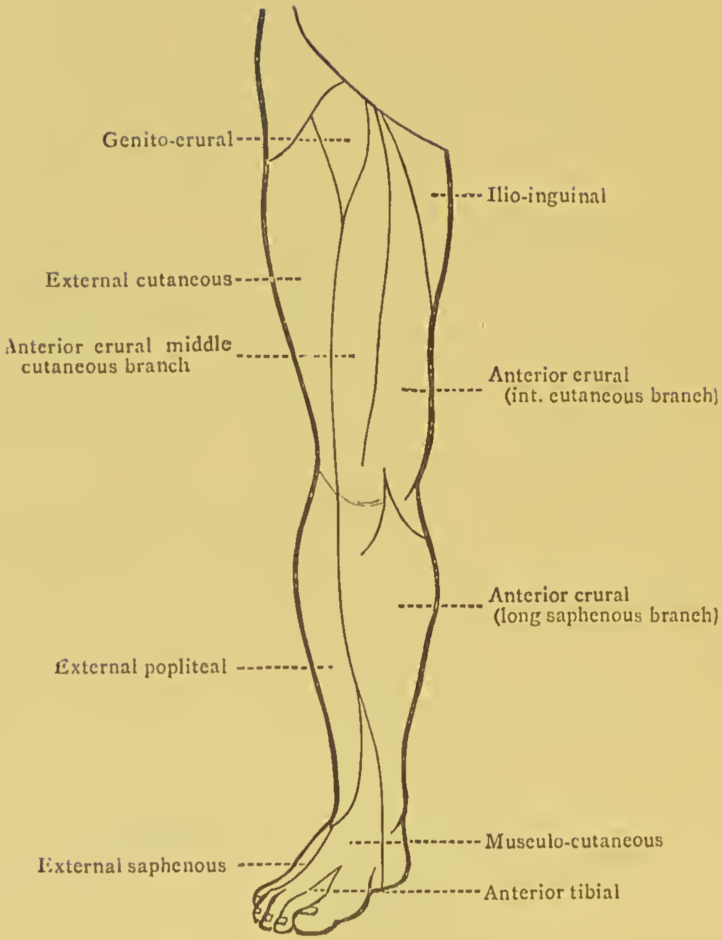
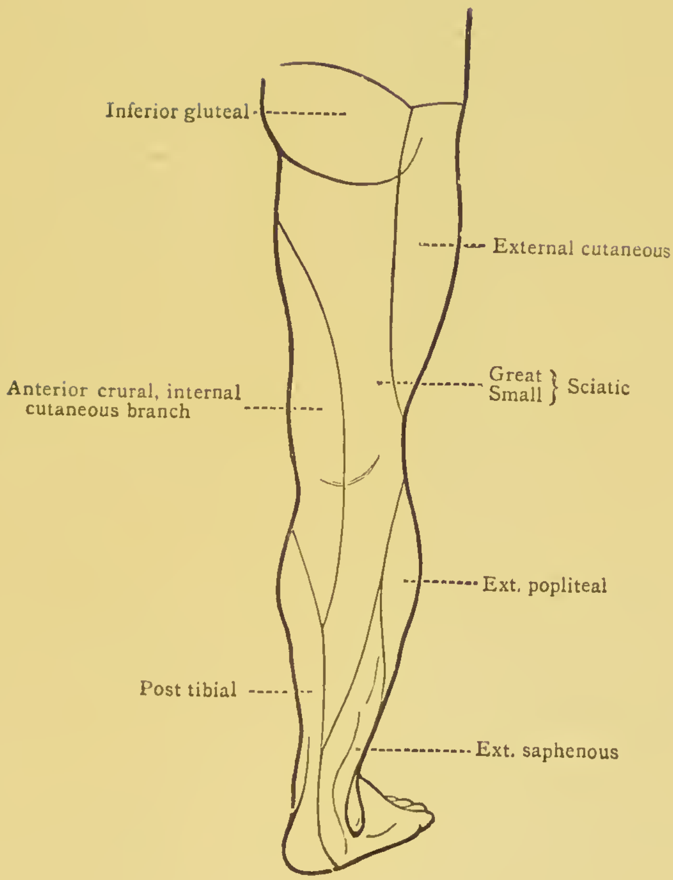

Supra-clavicular nerves
Circumflex
Musculo-spiral external cutaneous branch
Musculo-cutaneous
Median
Intercostal humeral
Lesser int. cutaneous
Internal cutaneous
Ulnar

PLATE X.



Genito-crural
Ilio-inguinal
External cutaneous
Anterior crural middle cutaneous branch
Anterior crural (int. cutaneous branch)
Anterior crural (long saphenous branch)
External popliteal
Musculo-cutaneous
External saphenous
Anterior tibial

PLATE XI.


Inferior gluteal
External cutaneous
Anterior crural, internal cutaneous branch
Great
Small
Sciatic
Ext. popliteal
Post tibial
Ext. saphenous

MM

INDEX.

December, 1903.

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